Proceedings of the Workshop on Stream Indexing for Salmon Escapement Estimation, West Vancouver, B.C., 2 - 3 February 1984

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PROCEEDINGS OF THE WORKSHOP ON STREAM INDEXING FOR SALMON ESCAPEMENT ESTIMATION, WEST VANCOUVER, B.C., 2 - 3 FEBRUARY 1984

by

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ABSTRACT

Symons, P.E.K., and M. Waldichuk (Editors). 1984. Proceedings of the Workshop on Stream Indexing for Salmon Escapement Estimation, West Vancouver, B.C., 2 - 3 February 1984. Can. Tech. Rep. Fish. Aquat. Sci. No. 1326: xv + 258 p.

The concept of using counts of spawning salmonids in a single stream, or sections of a stream, as indexes of the numbers spawning in other neighbouring or similar streams was discussed by about thirty Canadian and American scientists on 2 and 3 February 1984, in West Vancouver, B.C. From consideration of submitted documents and presentations by these scientists, the group drew various conclusions and made recommendations for management and research.

Some conclusions were: the required level of precision and accuracy of escapement data depends on its intended uses; inaccurate estimates of escapement cause a bias in recruitment assessments, which if eliminated might allow future yields to increase by 20%; some investigators believe that precision (consistency from year to year) is more important than accuracy of escapement estimates; stream indexing has been used till now with mixed success, and will not likely succeed in B.C., at least within the narrow definition of indexing given above; and recruitment to the fishery is better estimated by smolt counts than by estimates of escapement.

Some recommendations to management were: improve training of fishery officers to achieve consistency in escapement estimates; synthesize existing work on methods of monitoring escapement, some of which remain undocumented; study costs of various methods; concentrate on high quality data in a few streams in each district; increase funding; and research and document the historical data base now, while people who did the enumerating are still available to provide the essential background information on techniques used.

Recommendations for research included: assess and improve techniques for estimating escapement; and pursue the analysis of causes for different survival rates, between years and locations, of various life stages of salmonids.

Key words: salmon escapement enumeration, stock identification, recruitment, stock-recruitment relationships, stream indexing.

RÉSUMÉ

Au cours d'un atelier tenu les 2 et 3 février 1984 à Vancouver-Ouest (C.-B.), environ 30 scientifiques américains et canadiens se sont penchés sur le concept de l'utilisation des dénombrements de salmonidés reproducteurs dans un seul cours d'eau, ou une partie d'un cours d'eau, comme indices du nombre de géniteurs dans des ruisseaux semblables ou voisins. Suite à l'étude des présentations de ces spécialistes et des documents déposés par eux, le groupe a tiré diverses conclusions et formulé des recommandations pour la gestion et la recherche.

Voici quelques-unes des conclusions établies: le niveau requis de précision et d'exactitude des données sur la remonte dépend de l'utilisation prévue; des estimations inexactes de la remontée entraînent une distorsion dans le calcul du recrutement, sans laquelle il pourrait y avoir une augmentation de 20 % du rendement futur; certains chercheurs croient que la précision (constance d'une année à l'autre) des estimations de la remontée est plus importante que l'exactitude; l'indexation de cours d'eau a été utilisée jusqu'à maintenant avec un succès mitigé mais risque d'échouer en C.-B., au moins dans le sens étroit donné ci-dessus à l'indice; et le recrutement au stock exploitable s'évalue mieux à l'aide de dénombrements de saumoneaux que d'estimations de la remontée.

Pour ce qui est des recommandations à l'intention des gestionnaires, en voici quelques-unes: améliorer la formation des agents des pêches, afin d'obtenir des estimations constantes de la remontée; réaliser la synthèse du travail effectué jusqu'ici sur les méthodes de contrôle de la remontée, dont certaines sont encore non documentées; étudier le coût de diverses méthodes; recueillir des données précises sur un petit nombre de cours d'eau de chaque district; augmenter le financement; et examiner et étayer dès maintenant la base de données historiques tandis que les personnes qui ont réalisé les dénombrements sont encore sur place pour fournir l'information essentielle sur les techniques utilisées.

Pour ce qui est de la recherche, on a formulé les recommandations suivantes: évaluer et améliorer les techniques d'estimation de la remontée; et poursuivre l'analyse des causes des différents taux de survie, au cours des divers stades vitaux des salmonidés, en fonction des années et des emplacements.

Mots-clés: dénombrement de la remontée des salmonidés, identification de stock, recrutement, relation stock-recrutement, indexation de cours d'eau

ACKNOWLEDGEMENTS

We wish to thank all the participants for their positive response in accepting invitations, on such short notice, to attend the Workshop, to participate fully in the discussions, and in some cases, to contribute a formal paper for Appendix III of these Proceedings. While certain statements are attributed to a number of participants, noted in brackets in the Proceedings, the editors wish to emphasize that others also made positive contributions in the Workshop deliberations. The discussions were vigorous and all participants contributed, for which we are grateful.

We extend special thanks to Dr. C.D. McAllister, who painstakingly reviewed the draft Proceedings and made valuable and extensive suggestions for improvement. Any errors in documenting the discussions and the interpretations of individual presentations or comments, however, must remain our responsibility.

The Editors.

CHAIRMAN'S SUMMARY

The remarks which follow summarize some of the discussion and, more explicitly, the chairman's interpretation of that discussion. Other participants might have different interpretations. Moreover, not everything given in this summary was discussed at the Workshop.

The objective of the workshop was to bring together people working on salmon escapement estimation, management of salmon stocks and modelling of the population dynamics of Pacific salmon in British Columbia, and in the U.S. Pacific Northwest States and Alaska for exchange of information on their needs, approaches and findings. This objective was well met. The motive for the workshop was that we are embarking on a stream indexing program in the Fisheries Research Branch of the Pacific/Yukon Region of the Department of Fisheries and Oceans (DFO), and that it was considered useful, indeed essential, to hear about activities of others on this approach to escapement estimation and of its value to management of Pacific salmon. An index stream is here defined to be one in which salmon escapements are measured and used to estimate or predict escapements to nearby and similar streams located in the same drainage basin or biogeoclimatic zone, in which escapements are not directly measured.

Escapement data are required for fisheries management for a number of purposes which include: (1) to keep score on exploitation; (2) to assess the effect of exploitation on escapement; (3) to estimate stock-recruitment curves; (4) to forecast future recruitment to the fishery; (5) to achieve optimum egg-deposition by controlling the fishery; (6) to assess past and future effects and costs of habitat alteration and to identify the site of these effects; and (7) to document timing of spawning runs, which information is used to regulate fisheries or other human activities so as to avoid damaging the salmon resource. Not all these needs were discussed in the Workshop. But it was made clear that the required degree of precision and accuracy in the escapement data varies with the need. For example, it was suggested that the requirement for precision and accuracy of escapement data for impact assessment of habitat alteration is not great. Existing escapement data were considered adequate for this purpose, at least for the present. It was noted, however, that court cases involving habitat degradation may demand more precision and accuracy in escapement data in the future. For the purpose of establishing stock-recruitment curves and determining optimum escapement, the errors (30% or more) in existing data, except where fence counts are available, were considered too large.

By the end of the workshop, it was clear that stream indexing cannot be considered a panacea to better escapement estimates, as an aid to improved management of the salmon resource. There were indications, however, that forms of stream indexing have been used with mixed success in Washington, Oregon (index streams appear to work well for coho in this state) and Alaska (Cousens et al., 1982). The choice of the right base year was considered important in Washington State experience with indexing. For example, if 1981 had been used as a base year for Harris Creek, over-estimation by 90% could have occurred in escapement estimates for

adjacent streams in 1983. It was learned from the U.S. participants generally that estimates of escapements of individual stocks, obtained by as many methods as can be afforded, are used without necessarily applying indexing systems. Something that might be termed stream indexing is being pursued by the International Pacific Salmon Fisheries Commission (IPSFC) on the Fraser River system (e.g. counts in the Horsefly River and at Hell's Gate on the Fraser River), at least in terms of acquiring long-term escapement data obtained in a standardized, consistent way. The IPSFC noted that the potential of a given stream as an index stream must be evaluated and then a commitment made to monitor it continuously. Continuity is important. The British Columbia Fish and Wildlife Branch of the Ministry of Environment carries out a form of stream indexing for steelhead. Robertson Creek has been considered a success story in rehabilitating steelhead in the Somass River system, which was partly decimated by the net salmon fishery in Barkley Sound; but the Branch has not fared too well in indexing the Skeena River system's steelhead. The Branch is quite satisfied to use one index stream (Deadman River) to cover quite a large area in the interior of the province. Others said that site-specific information is important, although at least one participant suggested that in the absence of such information, certain salmon-production information from one part of the province could be useful in other parts.

The usefulness of an index stream appears to be not so much in its value for prediciting the size of salmonid runs to each and every individual stream in the same drainage basin or biogeoclimatic zone, but as a general indicator of what is taking place salmonwise in a river system or group of streams that the index stream or reach has been chosen to represent. It was noted in the report on Bristol Bay sockeye salmon in Alaska that changes in the Wood River lakes have been quite different for the different lakes and that the correlation is low (0.3 - 0.4) between individual lakes. However, if there is a small escapement in a particular stream, a small escapement can be expected throughout the system. It was suggested by the modellers that, while a high correlation is needed between the index stream and others in the area for a stock-recruitment relationship, the correlation need not be very high for ascertaining the general health of the system. Throughout the proceedings, it was stressed by various individals that long time-series are essential, and that the value of the data increases with the length of the data set. It was noted by the modellers also that precision (consistency) in escapement estimation is more important than accuracy. Long time-series of escapement are therefore of greater value when the estimates are made by the same individual year after year, using the same technique (this was stressed by the IPSFC in their 20 years of data at Hell's Gate), than when they are done by various people using different techniques. It was emphasized by several participants that the number of smolts migrating downstream is a more valid basis for determining the number of adult salmon returning to the spawning area at the end of the cycle than the number of spawners responsible for that year class.

Certain points made at the workshop on increasing the yield of the fishery were particularly intriguing. It was not made very clear by management

biologists how escapement data are used directly for managing the salmon fishery. The IPSFC did indicate that the escapement counts at Mission on the mainstem Fraser R., 60 km east of Vancouver, are vital for the manager on which to base in-season management decisions for adjustment of the fishery exploitation rate. It was also noted that counts at Hell's Gate, 25 km upstream from Mission, account for the removals by the Indian fishery and are used to adjust the gross escapement goals in-season to insure that net escapements are near the desired levels. Other indicators, e.g., the number of jacks returning in the previous year (this is useful for forecasting the size of runs a year in advance) and a test fishery just prior to the fishing season, were considered more important in determining the size of the run, the duration of the commerical fishery period to be allowed, and the fishery closure needed for an adequate escapement. This contributes to what has been termed a fixed harvest rate policy.

The modellers pointed out that over the long-term the yield of the fishery could be increased by as much as 20%, if a variable harvest rate policy were adopted and an escapement near the optimum were chosen. What the optimum escapement is for each stock is a key question. It was indicated by one of the participants that the optimum spawning stock in the Skeena River system is quite low. Area 3 (Nass River System) pinks exhibit a typical Ricker curve. An escapement of over two million pinks does not yield a better production than a substantially smaller escapement. It was suggested that stocks that are down should be increased by allowing a greater escapement, but the level of such increased escapement could not be defined until results from widely varying escapement have been observed over several cycles. In stocks that appear to be stable, some manipulation of escapement was suggested to determine if more of the salmon run could be allocated to the fishery, or if an optimum escapement for a maximum sustained yield had indeed been reached. The stock that dominates the catch can be used for determining optimum escapement. This could lead, of course, to overfishing the smaller stocks. In summary, it seems that we need a greater escapement at present, at least with some stocks, in order to derive the benefits of a greater yield, by as much as 20%, in the long-term (10 years) future.

A considerable amount of time was devoted, deservedly, to techniques of escapement enumeration. The old standby, for accurate and precise measurement, is still the counting fence, in spite of its various shortcomings, the major ones being that it is labour-intensive and that it can be washed out by floods. It continues to provide the standard by which other techniques are judged. With proper design, smolts as well as spawners can be counted at a fence. In order to count all the fish going up and coming down, the fence must be tended 24 hours a day, seven days a week, for the duration of the run. Used in this way, it is a labour-intensive facility. American fisheries biologists generally only count the number of fish going through for a 24-hour period once every few days, or once per week, and then plot escapement against days from the beginning to the end of the run. The area under the curve, in units of fish-days, then provides a basis for a reasonably reliable escapement estimate. In some instances, the start and end of a run are recorded, and then only the number of fish going upstream during a 24-hour period at the

peak of the run are counted. This provides a less reliable estimate than 24-hour counts every few days, because the shape of the curve of daily escapement vs. days is not known.

Other techniques are used for counting fish, but these are more subjective than fence counts and depend a great deal on the skill of the enumerator. By regularly "calibrating" estimates obtained by such techniques against results of an accurate method, i.e., fence count, the enumerator can adjust his visual count to be more in line with the real escapement. The less accurate techniques include: (1) walking the sides of the stream and counting carcasses of spawned-out salmon; (2) counting fish moving past a given point from a tower mounted high enough to allow the observer to see fish over the full width of the stream, or at least to a midway point, with the other side of the stream being covered by another observer on a tower on that side of the stream; (3) swimming the stream with snorkel or SCUBA gear for underwater viewing and counting; (4) counting fish in the stream from a raft or boat; (5) aerial surveys with a helicopter, counting the fish themselves or redds (these may have to be accompanied by other land-based techniques of counting for "ground truth"); (6) electronic counting, with systems such as side-scan sonar covering the side of the stream used by migrating spawners, or electronic detectors that count fish directed through narrow channels or orifices; and (7) mark-and-recapture programs.

Electronic counting devices have the advantage over a fence in that they need only be in place during the run of salmon and can be used on streams with large flows during floods when it would be virtually impossible to maintain a fence. Electronic devices can also count fish in turbid water, such as occurs in many of the glacial-fed streams in British Columbia and Alaska, where visual techniques fail. On the other hand, electronic counters require careful calibration against an established technique, preferably a fence count, to ensure that reliable data are being acquired. It was noted that 24-hour electronic counting of sockeye migrating to Hobiton Lake has improved the precision and accuracy of estimates expanded from visual counts, normally conducted only during daylight (estimated to record only 20% of the electronic count). Electronic counting did not reduce the amount of effort needed to make the counts. Electronic counts (Pulsar counter recording fish going through a narrow channel) have been used to calibrate visual counts on the Hobiton Lake system in order to back-calculate the earlier size of this stock, contributing to the Nitinat fishery, in an effort to reconstruct stocks from the earliest times for which some records are available.

British Columbia is perhaps unique in that enumeration of salmon escapement (except on the Fraser River system) is done almost exclusively by DFO fishery officers. There are some 1800 salmon streams in the province for which escapement estimates are provided. Not all streams supporting salmonids are monitored for escapement. The smaller and less accessible streams tend to be neglected because of limited time available for surveillance by fishery officers. The exception to escapement estimates by fishery officers in DFO-managed regions is in areas where fisheries research is being conducted or where more accurate escapement data are

required, as in development of certain salmonid enhancement projects. By and large, fishery officers carry out their enumeration by walking the streams, counting migrating spawners or carcasses, or both, and making an estimate of escapement in accordance with the system set up on the B.C. 16 forms (see Figure 1). The technique used for estimation of escapement is seldom specified in detail on the forms. Experienced fishery officers pride themselves in verifying their estimates at least occasionally by fence counts, but this is more the exception than the rule. Most fishery officers develop their own "tricks" for estimating escapement, but whether they achieve an accuracy anywhere near the real escapement is unknown. From comparison of stream-walking estimates with fence counts for sockeye in the Skeena River area, it has been found generally that the stream walking estimates are about one-third of the fence counts. It has been generally agreed that visual counts of coho, even by snorkelling, are only about 20% of the actual number of fish, because of the tendency of coho to swim under rocks, fallen trees, overhanging roots and under other forms of shelter.

There was some discussion in the workshop concerning stock identification, mixed-stock fisheries, effects of hatcheries on natural stocks and the problems that these pose in any type of stream indexing system in British Columbia. There are estimated to be about 1700 genetic stocks and 6000 management stocks in the province. Ten stocks account for 70% of the catch. The genetic stocks can be identified by a number of genetic characteristics, such as blood serum enzymes (monitored electrophoretically), meristic characteristics and scales. Unfortunately, most of these techniques require skill and are labour-intensive, and therefore expensive. Some stocks can be identified simply by the timing and duration of a run. Stock-specific parasites have proven to be useful tags for identification of certain stocks. A noteworthy example is the parasites used to identify three different stocks in Barkley Sound. A protozoan brain parasite, Myxobolus neurobius, and a protozoan flesh parasite, Henneguya salminicola, have been noted to be absent or to occur in different combinations in sockeye salmon from Great Central (neither parasite present), Sproat (Myxobolus present but not Henneguya) and Henderson (both parasites present) lakes, which are taken by the commercial fishery in Barkley Sound. The technique is elegant and, through the cooperation of nature in this area, is one of the best for stock identification found anywhere. Samples of the sockeye catch in Barkley Sound are now routinely examined annually for these parasites to determine, for management purposes, the proportion of the sockeye in Barkley Sound from each stock.

The importance of accurate ageing of fish to provide a reliable age composition of the catch was stressed by a number of participants. While scales are generally used for ageing by most agencies, it was noted by at least one group (IPSFC) that scales can be resorbed, or regenerated when lost, and hence give erroneous ages of fish. Otoliths were considered to be more reliable.

The seriousness of the fishery on hatchery-produced salmon in overfishing natural stocks was voiced by various participants. Many of the natural

stocks are being reduced to levels near extinction by overfishing during harvesting of hatchery stocks. The solution to the problem, in part at least, seems to be to have a terminal fishery, where fish are only allowed to be taken near the mouths of streams of origin. This would tend to avoid mixed-stock fisheries. It was noted that in Washington State, however, the strategy is to manage the fishery for the hatchery fish. In general, there was opposition among workshop participants to use of streams with hatcheries on them as index streams.

For a good assessment of the adult salmon yield from the spawn of a given escapement, it is essential to have, in addition to accurate escapement data, good catch data. These are not always available. The quality of catch data varies from species to species and may be as much as 30% in error. The sport fishery data may be quite inaccurate. Catch statistics from the Indian fishery may be incomplete. The by-catch of other species than sockeye by seiners may not be properly recorded. Poaching removes some of the fish that do not enter the statistical record, but the contribution of this illegal activity to error in the catch statistics in British Columbia was generally believed to be small. One of the participants estimated that catch statistics for salmon are generally within 10% of the real catch, even though the size of error depends on species.

Other factors were considered to be important in determining stock-recruitment relationships for Pacific salmon. It was noted that an estimate of the number of spawners is of greater value than the escapement, because some of the salmon migrating upstream may remain unspawned. The sex ratio, fecundity and egg retention must be taken into account in order to estimate egg deposition. The egg-to-fry survival may be very important in determining the recruitment arising from a given spawning. Experience in British Columbia has shown that egg-to-fry survivial may vary 200-fold and may not be density dependent. Washington State participants reported that their variation in egg-to-fry survivial is not as great. Ocean survival in the salmon's early sea-life stage can be a significant factor determining recruitment. The Oregon people have found good correlation of coho production with coastal upwelling. In British Columbia, it is believed that there are year-to-year variations in ocean survival of salmon, but so far no clear-cut correlation of salmon production with ocean variables has been established.

Some participants noted that streams in British Columbia have a way of increasing or decreasing independently of other adjacent streams when it comes to size of salmon runs and hence escapement. Experience of participants dealing with salmon stocks and escapements in this province showed that definite synchrony among stocks in year-to-year fluctuations occurred only in one area, namely Barkley Sound. This is a commerical sockeye area under careful management for which there are good catch and escapement data, because some of the lake systems contributing to the fishery (Great Central and Henderson Lakes) have been fertilized under the Salmonid Enhancement Program, and it is important to collect such data to determine the effectiveness of the lake enrichment program. Moreover, the parasite-tag technique of stock identification has permitted excellent

discrimination among the three major stocks of Barkley Sound (Great Central, Sproat and Henderson lakes). There is no evidence in Barkley Sound stocks, however, of cyclic fluctuations. An area showing suggestive evidence that abundance and size of juvenile salmonids vary synchronously in a geographic region are Carnation Creek and the four streams associated with it that have been studied for the last 10 years. Changes in escapement, however, do not appear to be important to smolt production over the range (43-176 spawners) investigated in the Carnation Creek study.

There was some discussion of the significance of errors in catch and escapement data. Modellers pointed out that random errors in catch merely move one up and down on the Y-axis, and are not as important to the stock-recruitment relationship as random errors in escapement. Such errors in escapement are crucial in that they produce a bias in the spawning stock size and underestimate the optimum escapement.

To my surprise, it was suggested that, except for chinook, the stocks of Pacific salmon coastwide are in reasonably good shape. Some non-chinook stocks have shown a decline, but others have increased in size, so that in total, the long-term change for British Columbia has not been that great. This optimistic note for salmon stocks generally was echoed by participants from Washington State, who noted that almost all their stocks have increased in the last 10 years. There was no positive solution offered to resolve the plight of the chinook stocks in the province, except to increase escapement and, as suggested by one participant, to consider indexing for chinook streams, including those served by hatcheries.

Finally, the salmon escapement data base in British Columbia, in spite of its deficiences in certain areas, provides a valuable record for a considerable length of time on the salmonid resources of this province. There is a need, however, to carefully analyse the existing escapement data, and where possible, determine their relative precision and accuracy, based on comparisons with high-quality fence counts and on discussions with the enumerators, and this should be done soon while these people are still available. Even if a better system is developed for escapement estimation, the fishery officers will continue to perform their valuable function in acquiring these data, possibly with improved guidelines for standardizing the enumeration system and thus improving the consistency. The practicality of stream indexing must be tested. It will necessitate careful monitoring for at least 15 years of several streams larger than Carnation Creek.

M. Waldichuk

1.0 INTRODUCTION

The Stream Indexing Workshop was held at the Park Royal Hotel, West Vancouver, B.C., on 2 and 3 February 1984. The workshop was hosted by the Department of Fisheries and Oceans and was chaired by Dr. M. Waldichuk of the Department of Fisheries and Oceans, West Vancouver Laboratory. Dr. P. Symons of Dobrocky SEATECH Limited, Sidney, B.C., was rapporteur.

In his introductory address, the chairman welcomed the 29 invited participants (Appendix II), presented the agenda (Appendix I) and asked for submission of written reports (Appendix III). In introducing the subject of the workshop, he drew attention to its full title, which stated that the indexing under consideration was "for estimation of salmon escapement". An index stream might be defined as one that is selected in a given drainage basin or geoclimatic zone to represent other streams with respect to salmon escapement and geoclimatic features (e.g., stream flow). A reach or section of stream which is carefully monitored may also act as an index. An index stock is one that reliably represents other stocks in the system. The chairman noted also that the discussions would not be confined solely to stream indexing but could range rather widely covering other aspects of streams, both biotic and abiotic, that affect their productivity in terms of salmon.

The format of the workshop was to be a general discussion following the outline of the agenda, interspersed with presentations of pertinent work by some of the participants. The chairman suggested the workshop would close by listing any conclusions reached, along with recommendations for management and research. When asked to whom the conclusions and recommendations would be addressed, he replied that they would be offered to the world at large or the scientific community, and more specifically, to anyone with interests in fisheries and problems of assessing escapement. With that, discussion of items on the agenda began.

These proceedings summarize the discussions that took place at the workshop. Some of the ideas and views are credited to certain individuals, who are noted in parentheses. Where more formal presentations are summarized, the papers submitted for Appendix III of these proceedings are also noted in parenthesis. Not all papers were formally presented in the workshop, but ideas derived from them by the contributors were used in discussions.

2.0 MANAGEMENT'S NEED FOR ACCURACY AND PRECISION

2.1 Consequences of Error

Management needs annual estimates of escapement for predictive purposes, to assess whether escapement required for optimum seeding or spawning in rivers is being approached or achieved (Harrison, Appendix III)*. The

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* Names in parenthesis indicate the person to whom the preceding statement or paragraph is attributed. Unattributed statements are a summary of several comments or a consensus.

accuracy of such estimates of escapement was questioned. There seemed to be a consensus that current methods could result easily in a considerable underestimate of escapement, and that, perhaps partly as a result of these underestimates, escapement goals were often not achieved.

Modelling work has been directed at trying to estimate the cost of different errors in estimates of escapement, assuming that the fishery is closed or opened according to those estimates. On this basis, when an estimate is 50% below the real escapement, the fishery loses about 20-30% of the yield it would have taken had the estimates been accurate. Some degree of error in the escapement estimates above or below the actual escapement could occur with virtually no loss to the fishery (Walters).

Biasses in estimates of optimum escapement occur with the current reporting system (see Walters and Ludwig 1981, and references in that paper). The method by which information is recorded on the B.C. 16 form (Figure 1) will apparently result in about a 30% average error in spawning stock estimate. Random errors of this magnitude are likely to result in a 50% downward bias in the estimate of optimum spawning escapement, that is, in the estimate of the number of spawners needed, or in the escapement goal (Walters).

The reporting system alone could lead, therefore, to an average 25-30% loss in average long-term yield. This could be avoided by improving the accuracy of escapement estimates, or, if this is too expensive, then by introducing a variation in the spawning status, by varying the harvest rate. With highly variable harvesting, even a serious error in estimates of escapement will result in little loss of yield over the long term (Walters).

There was a consensus that both accuracy and precision of current data are highly variable. Data from B.C. 16 forms could underestimate escapement by 30% to 50% and overestimate by 500% for sockeye to 1,000% for some other species. There is a need to standardize methods (in some cases methods are not even recorded) and increase the precision by standardization of escapement estimates, even if those estimates are inaccurate (Hyatt). For further discussion, see Section 6, Stock and Recruitment.

2.2 The Fraser River and International Pacific Salmon Fisheries Commission

The International Pacific Salmon Fisheries Commission estimates escapement to the Fraser River system by a variety of methods (Woodey, Appendix III). As sockeye salmon ascend to their spawning grounds, their numbers are estimated from acoustical monitoring at Mission, index counts at Hell's Gate fishways, and catch per unit effort by the terminal Indian fisheries. On the spawning grounds themselves, spawning populations are measured by visual surveys and mark-recapture estimates. Prespawning mortality is also estimated, and sampling is performed to obtain sex ratios and estimates of fecundity of the females and egg retention, since simple counts of spawners are themselves insufficient for estimating egg deposition. The data from

Government of Canada / Gouvernement du Canada
Fisheries and Oceans / Pêches et Océans

DISTRICT NO. .....

ANNUAL REPORT OF SALMON STREAM AND SPAWNING GROUNDS

YEAR .....

NAME OF STREAM (MAP NAME)	(LOCAL NAME)
FLOWING INTO	DATES STREAM INSPECTED

NOTE: A sketch of this stream is required on the back of this form, showing in addition to relevant data such as location of obstructions, general outline of topography along the stream portions of stream bed where spawning occurs, etc., its location in relation to some known point. These sketches should be brought up to date every five years.

PARTICULARS OF SPAWNING AND SPAWNING CONDITIONS – (Draw lines through names of salmon that do not frequent this stream.)

SPECIES	ARRIVAL IN STREAM	DATES OF DURATION OF SPAWNING			TOTAL NO. ON GROUNDS	SIZE OF RUN			BROOD YEAR SYMBOL	GIVE SEX RATIO IN %		
		START	PEAK	END		HVY.	MED.	LT.		M	F	JACKS
SOCKEYE												
SPRINGS												
COHOE												
PINKS												
STEELHEAD												
CHUMS												

NOTE: Estimate Number of Parent Fish on Spawning Grounds and indicate by placing letter in Column provided to show approximate number:

Thus: 1 - 50 A
50 - 100 B
100 - 300 C
300 - 500 D
500 - 1000 E
1000 - 2000 F
2000 - 5000 G
5000 - 10000 H
10000 - 20000 K
20000 - 50000 L
50000 - 100000 M
* Over 100000 N

* Where letter "N" used it is requested approximate number of fish on spawning grounds be shown.

PHYSICAL CONDITION OF SPAWNING GROUNDS

(A) Evidence of Erosion and Silting – Give Extent or % Stream Bed Affected .....

(B) Particulars of Scouring of Spawning Beds or Change in Course of Stream .....

(C) Water Levels (Low, Normal, High, Abnormal). If Abnormal, details should be given .....

BIOLOGICAL CONDITIONS

(A) Particulars of Distribution of Spawning Salmon over the Stream Bed .....

(B) Comments re Predators .....

(C) Evidence of Digging up of Eggs by Later Spawning Fish .....

OBSTRUCTIONS

(A) Passable or Impassable .....

If Nil, indicate from mouth to furthest point of access .....

(B) Nature of Obstruction .....

(C) Distance from Mouth of Stream .....

(D) Do you recommend that the Obstruction be removed? .....

(If so, attach report stating your reasons and describe nature and extent of the spawning grounds above obstruction)

COMMENTS ON ANY OTHER CONDITIONS AFFECTING THIS STREAM

.....

FP-0699

..... FISHERY OFFICER

Fig. 1. The so-called B.C.16 form. In reality, it is now an FP-0699 form, but its predecessor was labelled "B.C.16". The information required on both forms is virtually identical.

all sources must be integrated, then assessed with respect to about 25 different major stocks and a similar number of minor ones in the Fraser River system (Woodey).

Visual counts are kept as consistent as possible by employing the same techniques, and so far as possible, the same personnel for counts, but they still generally produce poor quality data. An expansion factor of 1.8 is used to raise visual estimates of Fraser River sockeye spawners to a population estimate. High densities tend to be under-estimated.

More reliance is placed where possible on mark-recapture programs and acoustic and electronic counting. Tagging rates may approximate 1% of the run, and recovery ratios 10-15% of the tagged fish. Higher recovery rates are difficult to achieve. Future work might be made more cost-efficient by using improved electronic equipment as this becomes available, but labour-intensive surveys of the Indian fishery, and mark-recapture programs would likely not be abandoned (Woodey).

3.0 FACTORS AFFECTING ESCAPEMENT

3.1 Management on the Skagit River

Management of coho escapement on the Skagit River (Washington) is imprecise; escapement may be as much as 70% under the goal, although at the other extreme only 10% over it. The most common causes for this failure are different timing of the runs from year to year, and the mixture of hatchery and wild stocks in the run. Reduced escapement resulting from overfishing through incidental catches is also a problem (Flint).

Stocks which include a significant hatchery component pose an added difficulty for management. Often overfishing of the wild stock occurs while management tries to achieve the acceptable harvest of hatchery fish. Tagging hatchery fish for identification and adjustment of escapement during the fishing season would help resolve this problem. The two management strategies are then to re-seed with hatchery stock where escapement goals are not achieved, and to encourage terminal fisheries where mixed stocks occur (Flint).

Discussion that followed the presentation on Skagit River salmon management, revealed that hatchery stocks may complicate management of escapement, particularly of steelhead, in the Fraser and Skeena rivers, and of coho and chinook in the Strait of Georgia. Catch of hatchery stocks now appears to be exceeding 50%, and is restricting the ability to obtain tagged hatchery brood stock for maintenance of hatchery output. Failure to mark sufficient hatchery fish hampers assessment of the seriousness of this problem, because the ratio of hatchery to wild fish in the catch remains unkown. Harvest rates must be reduced in the Strait of Georgia, but recovery even through use of hatcheries may already have been made difficult and expensive.

3.2 Management in Barkley Sound

In Barkley Sound, management of mixed stocks has been reasonably successful. There are three stocks of sockeye, as well as stocks of coho, chinook and steelhead. Stock-specific markers are needed, and parasites have been used for this purpose. Marking with tags is currently inadequate. Tags are expensive and recovery of tags, or decoding in the case of coded-wire nose-tags, requires time, which makes use of the information in the season of harvest difficult. Smaller stocks tend to suffer disproportionately from heavy fishing. In the case of steelhead, this is alleviated to some extent by the Robertson Creek hatchery (Hyatt).

With respect to stream indexing, there may be certain stocks or streams for which the technique is of doubtful use. For instance, small stocks or small streams, and certain species such as pink and sockeye, may not be indexable in any practical sense by relating estimated runs in one stream with those in others. Management decisions are needed, therefore, as to what sizes of stocks we can afford to disregard. This decision cannot be made without also deciding what degree of accuracy is required from the indexing information.

4.0 ACCURACY OF EXISTING ESCAPEMENT ESTIMATES

The accuracy of escapement estimates varies greatly (Table 1), depending on the species, the local habitats and the methods used to derive the estimates. Some of these problems are highlighted upon examination of historical data used to reconstruct the picture of stocks in Barkley Sound prior to the commencement of the lake enrichment program, and by various experiments and observations that have been conducted.

4.1 Barkley Sound

There are three major stocks of sockeye in Barkley Sound: those spawning in Great Central Lake, those in Sproat Lake, and those returning to Henderson Lake. The Great Central stock was enumerated prior to 1974-75 by visual counts of fish passing through fishways. Numerous groups, services, branches and departments have been in charge of conducting these visual counts over the years. The effort varied both in total hours of counting, and in the timing of counts. Electronic counters were installed in 1974-75, but without any cross-calibration. Electronic counts revealed that the timing of effort expended on earlier visual counts did not match the timing of the run, so that the earliest counts would have enumerated only about 40% of electronic counts. Later visual counts were better matched with the run and would have tallied 60-70% of electronic counts. A similar situation apparently existed at Sproat Lake, where electronic counters were installed in 1980, again with no consideration for cross-calibration (Hyatt).

In another lake, Hobiton Lake, the stock was assessed from the local fishing catches which took a high proportion of the potential escapement through the 1920's and '30's. The stock collapsed in the 1950's and

TABLE 1. Accuracy of various methods of monitoring salmon escapement indicated as approximate percentages of the number actually counted at a fence. The table is not exhaustive, and covers only studies reviewed during the workshop or reported in papers in Appendix III.

METHOD	PERCENT (%) COUNT AT FENCE					PROJECT	REPORTED BY
	Chum	Chinook	Coho	Sockeye	Pink		
Visual:							
Walking banks		20	1.5			Big Qualicum	Shardlow
		4-11				Harris Creek	Flint[1]
		9-17				tributaries	Flint[1]
Rafting/Floating		27	25			Big Qualicum	Shardlow
Swimming		50	65			Big Qualicum	Shardlow
Aerial				21-64		Wood River lakes	Rogers[1]
				8-37		Kerchak lakes	Rogers[1]
Unspecified				20		Hobiton Lake	Hyatt
B.C. 16 forms				8		Nimpkish Lake	Hyatt
Spawner curves			21-40			Harris Creek	Flint[1] [2]
			75			Oregon coast	Solazzi[1]
			48			Oregon coast	Solazzi[1]
	>80			80-95		Puget Sound Streams	Ames
Mark-recapture:			99-109			Minter Creek	Simpson[1]
				>120	140	Harris Creek	Flint
			92-112			Big Beef Creek	Simpson[1]
					127-165	Lakelse River	Simpson[1]
					117-144	Glendale River	Simpson[1]
				112-228		Lakelse River system	Simpson[1]
					268	Keogh River	Simpson[1]
				120-198		Babine Lake	Simpson[1]
				103-115		Cultus Lake	Simpson[1]
				100-196		Williams Creek	Simpson[1]
				152		Scully Creek	Simpson[1]
Acoustic:			82-120			Great Central Lake	Hyatt
			90-110			Hobiton Lake	

[1] Details available in report presented in Appendix III.
[2] Note: "Selection of a particular 'base year' escapement can have dramatic effect on escapement estimates".

fishing ceased. From 1952 to 1966 there were spot-checks on spawning escapement. Between 1967 and 1980, there were systematic visual surveys, and since 1980 counts at a fence. Lake fertilization commenced around 1977, just prior to the improved estimate of escapement, and these counts showed a higher escapement than previously estimated, making lake enrichment appear very effective.

However, a re-assessment of earlier data revealed that visual surveys probably accounted for no more than 20% of true escapement at that time. The effects of lake enrichment, while uncertain and less than at first seemed to be the case, are probably still significant (Hyatt).

Acoustic surveys of juveniles in Great Central and Hobiton lakes also revealed that escapement must have been considerably higher than that suggested by visual counts, since, given normal survival rates, the minimum numbers of juveniles considerably exceeded those counts. These acoustic surveys of juveniles are capable of predicting smolt output within 20% of numbers counted at a fence, and adult escapement within 10% of those enumerated at a fence. Adult escapement is estimated from known sex ratios and fecundity of females, and assumed survival rates from egg to the young stages surveyed. In Nimpkish Lake, estimates derived from the B.C. 16 forms may be as little as 8% of escapement estimated from acoustic surveys of juveniles (Hyatt).

Discussion of the estimates for these lakes revealed that fishery officers completing B.C. 16 forms often record what they think is in the river rather than what they see (Hyatt). Even if this results in a more accurate estimate of escapement, which it may do, it reduces precision and virtually destroys any comparability between estimates from different fishery officers. Although more streams may now be enumerated than previously, the system of enumeration is generally not recorded and is variable from a stream in one area to a stream in another area and sometimes from year to year in the same stream because of rapid turnover of fishery officers. The choice appears to be either to document and standardize visual count methods using the B.C. 16 forms, or to abandon such methods (Hyatt).

Even where the same methods are used by different agencies on the same system in the same years, the correlation between visual estimates, though present, reveals a great lack of precision. This is true, for example, for helicopter surveys carried out by two services which make estimates of spawners on Morice Lake. The variance was said to be high (Hyatt).

4.2 Harris Creek, Puget Sound

Harris Creek has been used for some time as an index stream for coho escapement to other streams in Puget Sound. A weir on the stream enumerates adults (and smolts are also trapped on their way out). Visual counts of adult coho along about 0.8 miles of the main stream were about 20-40% of the number counted through the weir or estimated from mark-recapture data when the fence was occasionally washed out. The correlation between visual counts and weir counts was good, both in Harris

Creek itself, and its tributaries. Various estimates of escapement were assessed for their value as an index, and the total peak count was found to be best, though intuitively the estimate from the area under the curve in a plot of fish per day against days would be expected to be better (Flint, Appendix III). Estimates based on areas under the curve give units in fish-days which are an abstract number useful for comparative purposes. The estimate of escapement in a stream, based on an index stream, can vary tremendously, depending upon the base-year chosen. If a low year is chosen, the escapement in normal years could be overestimated by 90%.

The use of redd counts was discussed. These were considered extremely difficult to interpret where more than one species of salmon occurred in a stream, even where densities were low enough that individual redds could be distinguished. No attempt to compare redd counts with weir counts was made in Harris Creek.

Mark-recapture estimates often overestimate escapement because of tag loss. The degree of error depends upon the species and undoubtedly other factors, but a review of about 30 comparisons between mark-recapture estimates and fence counts led to the following generalization: Mark-recapture studies over-estimate: sockeye by 20% (conservatively);
pink by 40%; and
all species combined by 26%.
The variability is large. Taking all species together, the 95% confidence limits on relative error range from 14% to 48% and the accuracy of estimates ranges from being almost correct to being three times too high, or 200% in error. The use of a fence to increase recovery rate of tagged fish can reduce error by about 15% (Simpson, Flint).

4.3 Lakelse and Babine Systems

In a study by M. Shepard on Lakelse Lake sockeye salmon, where 75% to 85% of tags were recovered at a fence some distance above the tagging site, the overestimation by tagging in three replicate years varied from 12% to 128% (Simpson, Appendix III). At Babine Lake, methods were more variable, but overestimates ranged only from 20% to 100%. Here mortality between marking and recapture could have occurred. On Lakelse River in another study by H. Smith, when marking of pink salmon was done adjacent to the spawning grounds, the overestimation was from 24% to 44%. Not only does mark-recapture overestimate, but the degree of error may vary unpredictably from one year to the next, and it is perhaps this that is most disturbing (Simpson).

In an early paper by R. Brett (1952) on the Skeena River system, it was concluded that if fence counts were taken as 100, mark-recapture estimates were 200 and stream visual counts were about one-third, or 33% (Waldichuk).

Visual estimates, when compared with removal estimates over short sections of streams, revealed that about 75% of adults were seen, with little

variation. With respect to jacks, however, variation was high, ranging from 12% to about 60% seen. The number of logs, cover and so forth may influence these visual estimates (Solazzi).

4.4 Big Qualicum River

Experiments have been carried out on Big Qualicum River to assess the accuracy of escapement estimates made by a variety of methods. These methods included walking, rafting, snorkeling and strip counting, all performed by a variety of personnel with varying experience. Both pools and riffles were surveyed separately from a survey of the river itself. Estimates from helicopter flights were also assessed. The results were compared with the number of fish known from electronic counts at a fish passage (Shardlow).

People were asked to record the number of fish they saw and the number they estimated to be present. The number of chinook seen while walking was 20% of the total present, while that estimated was 40% of the total; the proportion seen while rafting was 27%, and estimated was 40%; the proportion seen by swimming was 50%, and estimated was 60% of numbers present. For coho, a smaller proportion was seen while walking, about 1.5%, and by rafting 25%, but 65% were seen by swimming. Chum salmon were also present, but the results from this species are not yet available. Fishery officers, biologists, secretaries and housewives were equally accurate, provided that they had the benefit of some previous experience (Shardlow).

5.0 STREAM INDEXING FOR ESCAPEMENT ESTIMATES

By "stream indexing", most people seem to mean the use of one stream in which stock and recruitment relations, and movements of adults in and juveniles out, are examined closely to provide information on other similar streams with the same biophysical characteristics. The degree of effort expended in the index stream may vary from simple visual counts made from the stream bank to accurate fence counts. Likewise, in the other similar streams which are being indexed, efforts to estimate escapement may vary from none to reliable fence counts. The studies discussed in this section fall across this spectrum (Table 2). The best test of stream indexing occurs, of course, when reliability is high in both the index stream and the streams being indexed.

5.1 Carnation Creek, Vancouver Island

Production of salmonids has been intensively studied in Carnation Creek (Holtby et al., Appendix III), a small stream on the west coast of Vancouver Island, with the objective of assessing how forest harvesting may affect that production. As with any intensive study on a single system, the representativeness of Carnation Creek for other streams has been a concern. As a part of the study, therefore, coho populations were assessed in short sections of three other streams in the area. Some of the results

TABLE 2. Subjective classification of studies reviewed at the workshop according to reliability of indexing and indexed streams, where such classification is appropriate[1]. Number before project refers to section in which project is reported.
(c= coho, s= sockeye, p= pink, h=steelhead, t= cutthroat trout)

Reliability of estimates in index stream	Reliability of estimates in streams being indexed		
	None[2]	Low	High
Low[2]	5.3 Puget Sound[p]	5.5 Bristol Bay[s] 5.6 Oregon 5.4 Washington	
Medium	5.3 Puget Sound[c]		
High	5.3 Puget Sound[s]	5.1 Carnation Creek[ct] 5.7 Keogh/Quinsam[h]	5.7 Keogh/ Quinsam[c]

[1] Reliability of estimation of escapement may vary in both the index stream and stream being indexed.

[2] Criteria:
- None - no effort is made to count escapement; expansion of index figure is based on relative size/area of spawning ground.
- Low - visual counts or other methods which enumerate only a portion of the run.
- Medium - tagging studies or other means of estimating total run; total counts where method has period of failure with no back-up.
- High - total counts of escapement through fences or fish passes where periods of failure, if any (fence washout, electronic failure) are backed up by secondary methods such as tagging.

of this study should be of interest in assessing the validity of the concept of "index streams" (Hartman).

First, although the data from Carnation Creek on adults entering and smolts leaving are by no means perfect, they are of as good a quality as to be found probably anywhere. Despite this, the relation between escapement and smolt output is variable (Hartman).

Second, the sizes of juvenile populations of 0^+ and 1^+ coho in Carnation Creek and in the three other streams reveal a general pattern in which the numbers of both age groups tend to go up or down together, that is, they are loosely correlated. There is some evidence of the same thing for cutthroat trout. The correlations, however, are poor. If Carnation Creek were used as an index stream, estimates of what was happening in the other streams would be accurate only within about 50% (Hartman, Holtby).

Lastly, with respect to assessing numbers of adults entering the stream, timing of entry varies from year to year, entrance tending to occur with storms. If entrance has been delayed because of adverse conditions, the entire run may enter within the space of a few days. With this kind of variability, there would seem to be little or no validity to the idea of using an index stream or streams for estimating overall escapement (Hartman).

If a stream is considered for indexing purposes, not only must the coming and going of fish be monitored closely, but conditions within that system must also be measured, because these too alter stock-recruitment relationships. For instance, in Carnation Creek the relation of one- to two-year old smolts was originally approximately 50:50, but this has changed currently to 80% one-year olds. Because the size and survival of smolts of different ages are likely to be different, the recruitment to the fishery and its management would also have to be altered appropriately (Hartman).

Given the degree of variation seen within and between streams, the abundance of clams on west coast beaches might be as good an index of escapement as any other, considering that both clams and salmon over the long term, are influenced by oceanic conditions (Hyatt).

5.2 Cook Inlet, Alaska, and Sonar Fish-Counting Equipment

Bendix side-scanning sonar equipment has been used in Cook Inlet, Alaska, to enumerate salmon entering some of the rivers there. This equipment is particularly useful for enumerating sockeye salmon which normally keep close to the shore when migrating upstream; it may be less useful for other species (chinook, chum and coho) which do not follow the shore so closely. The equipment and counter cannot distinguish between species, and may also count debris although the mechanism can be tuned to some extent to count only fish-like sonar reflections. The equipment does not reduce manpower requirements or costs, but does permit a more accurate enumeration in circumstances where other methods are limited, such as a large (but shallow) river with murky water. Costs of the equipment currently run from

$30,000 to $50,000 (U.S.), or about $75,000 in Canada. Accuracy, when the equipment was calibrated, was found to be as high as 85% (King, Appendix III).

In discussion on fish counters that followed, it was noted that another sonar system in use is the Pulsar system, which is relatively cheap ($6,000 each)(Hyatt). Fish must be channelled through a specific location, and the accuracy of the count depends on experience of the crew and care they take to calibrate the equipment. The equipment saves no money, but does improve accuracy.

At the entrance to the Nadina River spawning channel on the Fraser River system, a sonar counter was used, but without constant surveillance it was operable only about 20% of the time (Woodey).

At Hell's Gate, a counter using the Doppler effect has been tried and appears promising, though water turbulence has given some trouble. It can operate with only a daily check (Woodey).

5.3 Streams in Puget Sound, Washington

In the State of Washington, the so-called "Boldt decision" required rapid assessment of salmon stocks in that state. Various methods were used to survey standardized stream areas (index streams) to obtain figures on relative abundance of spawners. Over the years, accuracy has been recognized as a problem and various methods were devised to improve accuracy. Current methods used in Puget Sound include: counts made on foot, by boat, and by air; counts at traps, weirs, and fishways; electronic counts; and tag-and-recovery estimates, both of live fish and carcasses.

The best method used to date appears to be the development of a spawner curve from visual counts, but the method is limited to areas of relatively good visibility. Periods of inclement weather and high discharge may create large gaps in the data, which are difficult to fill and may raise doubt as to accuracy (Ames, Appendix III).

The best estimates are obtained on sockeye salmon. A comparison of methods was made on sockeye entering Lake Washington. These methods included counts at the locks, tower counts on the river and acoustic counts. Visual data were converted to estimates derived from area under the curve of number of fish vs. days, assuming a 15-day life of spawners. All estimates came within 10-15%, and regressions accounted for 95% of the variability, until recently, when visual accounts began to account for only about two-thirds of the sockeye counted through the locks (Ames).

After sockeye, chinook are the easiest species to enumerate, followed by chum. Coho and pink are the most difficult. Chinook escapement has been estimated from redd counts. Estimates from tagging were only 20% higher than estimates from redds (Ames).

Visual counts on chum salmon in index streams are performed at seven-day intervals. Estimates are then made from the area under the curve. These

estimates are expanded to provide estimates of numbers in large systems where chum salmon cannot be counted. Area-under-the-curve evaluation probably underestimates escapement. Adjustments are made for visibility, but with unknown success (Ames).

Coho estimates are poor simply because there are about 5,000 miles of streams utilized by this species in Puget Sound, and this is too big an area to survey. Perhaps 5% of spawning areas where densities are highest are visually inspected. Resulting estimates are checked with tagging studies, and the revised estimates are expanded for the entire area (Ames).

Pink salmon estimates are probably the worst. Escapement is probably seven to eight hundred thousand fish. Over 80% are concentrated in three major river systems, and counting them is impossible. Carcass counts are made, but with little confidence (Ames).

5.4 Other Streams in the State of Washington

On the west coast of Washington, the Quinault Indian Nation estimates escapement to some index streams by counting redds through the season. Then this is expanded to the other streams by doing a single count of redds in 60-70% of these streams. Smolts are also trapped and tagged on the index stream, tag-recapture data giving an index of the total smolt population (Lestelle).

On the Quileute River system on the west side of the Olympic Peninsula, efforts are being made to improve sampling strategies to conserve financial and manpower resources (Newman, Appendix III). Coho redds are counted on index streams, and then the number is expanded to give total number of redds throughout the system. Various strategies are being studied. Inclusion of low productivity streams amongst index streams is discouraging for those persons who must count the redds, and may result in variable search effort between streams (Newman).

5.5 Streams Tributary to Bristol Bay, Alaska

In Bristol Bay, Alaska, sockeye stocks have been followed in most major rivers since the 1950's (Rogers, Appendix III). Escapement has been estimated by aerial surveys for the past 30 years. Keeping this survey going through such a long period of time has been difficult. Escapement goals are now set for each system, and the level of escapement depends to a great extent on whether the particular stock remains at sea for two years or three years. Escapements have increased dramatically recently, especially among stocks that stayed at sea three years. This is apparently so because three sea-year stocks have been more seriously depleted by the fishery than two sea-year stocks, and they must be allowed a higher escapement. Correlation between spawning grounds is poor, about 0.3 or 0.4. Index streams or reaches would therefore give a very poor idea of what was happening in other streams, unless some of the larger stocks are chosen as the index. There are about six stocks which provide about

two-thirds of the total. The question of cycles has been recently re-examined and previous theories are thrown into doubt. The determining factor now appears to be management and level of escapement allowed through the fishery. The contribution of small stocks to the total is very difficult to assess (Rogers).

Tower counts have been correlated with flight surveys. Where densities are high, tower counts are approximate. Variation between tower counts and flights averaged 1.5 to 20% over eight years, but in the ninth year there was a discrepancy of 60% (Rogers).

Often the potential productive capacity of a stock is not recognized until it is observed through an accidentally large escapement. There is now some consideration given to increasing escapements to increase yields (King).

5.6 Streams in the State of Oregon

In Oregon, estimates of spawners in selected reaches are compiled to give indexes of total escapement (Solazzi, Appendix III). Areas are used where fish are concentrated. Streams are surveyed on foot once per week to give an area-under-the-curve estimate. Streams that might be influenced by hatcheries are avoided. Estimates suggest that surveyors see 75% of adult coho and 48% of jack coho that are estimated to be present by the removal method. Even though the prediction capabilities appear excellent, a decline in the fishery has not been avoided. Managers have asked for still greater accuracy, and want the very successful index system replaced with actual counts that will give accuracy to ± 10% (Solazzi).

5.7 Application of Stream Indexing in British Columbia

Index streams would probably not be useful in British Columbia. They might be used as a last resort, but variation between streams must first be checked. In the past when this was done, variation was usually too high for indexing to be practical. The lack of relation between streams was documented through work on fenced streams, but because the results were negative, they were neither published nor publicized (Simpson). The "key" stream idea, similar to stream indexing, was raised, examined and abandoned years ago (Waldichuk).

A workshop on design of a salmon escapement monitoring system for British Columbia held in October 1982 (Hilborn 1983) concluded that most species of salmon are not amenable to management by stream indexing, although coho may be an exception. The success with coho was due in part to visits by fishery officers to every stream. This emphasized that to use index streams effectively, information from the other streams was needed to indicate how the extrapolation was to be made. For sockeye, pink and chum, a few stocks contributed almost all the fish, and it was concluded that all major stocks must be examined in detail; indexing was not appropriate. Because coho are so widely distributed this approach is not possible. The hook-and-line fishery on many mixed stocks of coho can only be managed on

an annual basis; seasonal closures are less important than for net fisheries targeted on specific stocks.

Indexing can take several forms and may be done for several reasons. Using one stream as an index to cut costs may be practical if the objective is simply to know if escapement is going up or down, but if more accurate estimates of escapement are required, the method is inadequate. For use in stock-recruitment management, the correlation between streams is far too low.

Another concept is the use of index reaches on streams, for indicating escapement to the whole stream. Here indexing may be practical, since the level of precision can be expected to be higher.

Precision and accuracy may be increased by using a set of index streams rather than a single stream, and/or by increasing the information available on the streams to which the data from the index stream are to be extrapolated, but problems of subsampling and level of effort must be resolved. The question of costs of surveys may have to be related to the value of the resource. The ratio of benefits to costs may be increased with experience and with improved techniques, but the variability between streams remains a problem.

Three streams in the Skeena system, which were very close geographically, showed no relation between them with respect to numbers of pinks and sockeye utilizing them (Bams). The degree of variance between streams probably varies between geographic regions and between species. There is a close relation between variation of sockeye runs to Sproat and Great Central Lakes, but escapement to small streams in the same area may be completely independent (Hyatt). Again, the use or purpose of indexing must be carefully identified: in Sproat and Great Central lakes, the objectives for management may be achievable; elsewhere, they may not be.

Enumerations have been made at weirs and fences on the Keogh, Quinsam and Little Campbell Rivers, and sizes of runs appear to coincide. The first two streams are on northern Vancouver Island, the last is on the lower mainland. In the interior, Deadman River is used as an index stream. These index streams give an indication of the strength of runs. The catch data from recreational fisheries seem to correlate well with the impression from these index streams, and there seems to be justification for use even of a single index stream for indicating the general status of steelhead in an area as big as half of Vancouver Island (Slaney).

The need to test the practicability of stream indexing is paramount should the concept be considered seriously. It will require careful monitoring of escapement to several streams bigger than Carnation Creek, and will need continuous financial support for as long as 15 years. Whether managers would use the information from such a long-term experiment even if it were available is uncertain, but from experience, what is certain is that their most persistent question would be "when are you going to quit?". The two important questions at this point are: "How good is the concept?" and "How would it be used?" (Hartman).

Some answers to the second question of how stream indexing might be used are:

1. To keep score on exploitation;
2. To assess the effect of exploitation on escapement;
3. To estimate stock-recruitment curves; and
4. To forecast future recruitment to the fishery (Starr).

To utilize index streams for these purposes, information must be gathered on individual stocks. There is also a need to relate escapement to catch, but this cannot be done by indexing unless catch is estimated independently. To do this, tagging with coded-wire nose-tags would be necessary (Starr). For coho and chinook, hatcheries may function as index streams since they already contribute a large proportion to the fishery, and the fish are reasonably well marked (Starr). However, there was some disagreement among participants as to the usefulness of hatcheries for this purpose. For chum, pink and sockeye, stream indexing would probably not work, at least not within the narrow definition given in the Introduction.

Before managers will be willing to support the effort necessary for useful indexing, they will want some idea of the potential of the river systems under consideration for production. When there is good potential for improvement of production, support may be available from hatcheries and from fishery officers, which managers are not using. We could make better use of this information. Fishery officers perform functions in addition to estimating escapement, and any thought of replacing fishery officers with a stream indexing system should be discarded (McAllister).

6.0 STOCK AND RECRUITMENT

6.1 Stream and Lake Survival of Fry and Smolts

The relation between escapement and recruitment to the fishery is loose, and may be of limited use for predicting yields to a fishery. Egg-to-fry survival of pink and chum salmon in various streams has varied from 0.1% to 22%. It is understandable, therefore, that a count of fry or of smolts, as at Carnation Creek, is a more accurate predictor of recruitment and yield to a fishery than is a count of spawners. A count of spawners itself is better than a count of escapement, since much may happen between return of salmon to the stream and spawning. The conclusion is that for estimating or predicting recruitment, stream indexing for escapement would be useless, and should not be undertaken (Bams, Appendix III).

Modelling has been used to investigate the effect of errors in estimates of catch and of escapement on the management of stocks. Management is assumed to occur through manipulation of escapement, since this is, in effect, the only point at which a stock can be managed. Errors may be random or

systematic. Random errors or "noisy data" result in an apparently poor relationship between stock and recruitment. Under these circumstances, the management strategy would appear to be to allow as small an escapement as possible for optimum yield, since this gives the best yield-per-recruit ratio. This is a standard problem. Noisy data will always underestimate escapement requirements (Hilborn).

Random errors in catch make little difference, but random errors in escapement make a large difference, since they flatten the stock-recruitment curve and cause the underestimate of escapement requirements just discussed. Suprisingly, even if there is no error in spawning and recruitment estimates, the optimum escapement is still underestimated because of the statistical procedures employed (Hilborn).

Systematic errors cause problems too, but such errors are more likely in catch estimates than in escapement estimates. Systematic errors in catch may arise from the apportioning of catches to different stocks. Here the contribution of small stocks is systematically overestimated. Errors in escapement resulting from poor accuracy are relatively unimportant since they merely shift the curve up the Y-axis. An error of 50% below or 100% above the true escapement would probably matter little. Regarding escapement errors, estimates of average freshwater life or turnover rate may contribute a systematic error. Ageing errors can contribute to systematic errors both in recruitment and escapement (Hilborn).

Replicability of estimates of escapement and recruitment in good studies (those with intensive tagging and recovery, or more accurate methods) is about 20% to 30%, and this may be adequate. Further modelling studies are needed to decide this.

An assumption of time independence in a series of data may be false. In fact, time-dependent changes can occur. The stock-recruitment relationship on the Skeena River has changed over time. This occurred because of elimination of unproductive stocks with continuous fishing. The result was fewer, more productive stocks.

In sum, these random and systematic errors when assessed suggest that we are currently overharvesting, and the yield in the long-term could be increased by 20% by decreasing harvesting effort. The requirements for management on the basis of stock/recruitment curves, which is really the only legitimate method, are stringent, and the errors contribute to management for too small an escapement. Errors can be reduced by calibration techniques, and their effect could be further assessed through modelling. Management for information retrieval, by deliberate manipulation of the stock, may be a practical means of obtaining a reasonable stock/recruitment relation quickly (over a few rather than many years). However, the costs of such manipulation to the fishery must be assessed, and in fact, they may not be warranted by the potential 20% increase in harvest that would be obtained only in the long term (Hilborn).

6.2 Early Sea-Life Survival

The usual figure used is 10% survival from smolt to returning adult, but obviously this could vary. Higher survival will increase escapement. In the early '60's, chinook salmon catches decreased enormously. This was one cycle after the 1958 El Niño occurrence, and the hypothesis is that the warmer water in that year resulted in a low survival of chinook smolts (Starr).

6.3 Identification of Stocks

Stocks can be discriminated according to species composition of their parasites, and the three main Barkley Sound stocks can be discriminated according to the frequencies of two parasites. The precision, however, may be poor. Precision may be improved by combining parasite information with the timing of runs, with examination of scales, and with electrophoretic studies, though the latter have shown a low capability to discriminate Barkley Sound stocks (Hyatt).

In the United States, electrophoretic studies have been used with some success in Puget Sound, but the method is expensive and budget cuts have necessitated curtailment of its use. The distribution of hatchery-reared coho and chinook to different streams has virtually destroyed the usefulness of this approach for this species in certain areas (Ames).

Scale sampling and analysis is one of the cheapest methods of stock identification. With respect to sample size needed for proper stock identification, however, up to 100,000 fish have been sampled in some years, and discrimination has still been low (King).

The level of discrimination required depends on what question is being asked. No general figure for accuracy could be proposed.

6.4 Catch Data and the Problem of Accuracy

The number of fish buyers in the Puget Sound area has increased enormously in recent years. Buyer boats may visit several areas, so that origin of fish sampled at the docks is unknown. The number of buyers has increased from 20 or 30 to 700. These two factors have made useful sampling much more difficult (Flint).

The reliability of catch estimates varies with the species. Estimates for chinook salmon are much worse than for sockeye salmon. In the Strait of Georgia, estimates of catch of pinks and chinooks were made recently by two methods, and these showed that estimates from fish tickets were probably 30% below the actual catch, as estimated by catch per unit effort. The catch is split by size and sold to different markets, further complicating the sampling. Indian food fisheries, some sport fisheries and by-catch of juvenile salmon in seine fisheries are not included in current catch estimates, further contributing to a serious underestimate of total catch. Poaching is probably a relatively minor problem (Starr).

For the ocean troll fishery, the estimate of catch from sales slips is probably within about 10% of the correct value (Starr).

6.5 Habitat Protection

Some of the uses to which escapement data can be put with respect to habitat protection include:

- to identify threatened or damaged spawning grounds;
- to identify migration routes both of adults and of juveniles which may be threatened by both large- and small-scale environmental disturbances;
- to identify timing of runs;
- to index the use of estuaries by young fry (the level of precision needed here is low);
- to estimate the dollar value of fish habitat when it is in competition for use with other resources;
- to estimate the degree of habitat damage or destruction over long time periods (McAllister).

It is difficult to see how a stream indexing program would address any of these needs. Current data, even from the individual streams or habitats in question, may be insufficiently precise for some of the purposes to which the Department of Fisheries and Oceans Habitat Management Division has put them, but so far industry seems to have accepted this situation. In effect, the statute (Fisheries Act) does not require accurate statistics. A recent case involving a cutthroat trout population was challenged on the basis that the stock was not supporting a fishery. However, challenges by industry more often concern understanding of biological processes rather than the accuracy or precision of statistics.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Some participants at the workshop noted that they already use stream indexing in various forms for specific purposes in specific areas. It is not currently more widely used because those in the business consider that a wide-spread stream indexing program would serve no useful purpose. Stream indexing is simply one of several available tools whose usefulness depends upon the objectives of the work. In the absence of carefully considered broad objectives, the following conclusions concerning the use of escapement estimates and recommendations for improving estimates of escapement by a variety of methods were put forward.

7.1 Conclusions

1. Escapement data are put to different uses. Each use requires different precision and accuracy.

2. Precision (consistency) of escapement estimates is more important than accuracy for defining long-term, stock-recruitment relationships.

3. Inaccurate escapement estimates cause bias in stock-recruitment assessments, by making recruitment appear to be independent of escapement, so that there appears to be no loss due to decreasing escapement or improvement due to increasing it.

4. By eliminating bias in assessment of how escapement levels affect production, accurate counting systems might allow future yields to be increased by as much as 20% (since we would be better able to determine which systems currently have over- or under-escapement).

5. Stream indexing has been used with mixed success for estimating escapement in the states of Washington, Oregon and Alaska:

   - In Washington, "stream reach indexing" is used for a variety of salmon stocks to estimate escapement and manage fisheries;

   - In Oregon, stream indexing has been useful to document trends in escapement of coho and chinook salmon, but has not prevented a decline;

   - In upper Cook Inlet, Alaska, stream indexing, when used to measure magnitude of escapement, has been unsuccessful.

6. There was a consensus that use of one stream to estimate escapements in several nearby and similar streams would be unlikely to succeed in B.C. However, other stream indexing techniques may have successful applications.

7. Recruitment is better predicted by smolt counts than by estimates of escapement, since variability in survival of eggs, fry and parr prior to the smolt stage is so great as to make prediction of recruitment from escapement estimates useless in some cases.

7.2 Recommendations

The participants in the workshop agreed that the recommendations should be divided into those for management and those for research. It was also agreed that the recommendations given in the notes from a workshop of 4-6 October 1982 (Hilborn 1983) are still relevant for management and therefore are reproduced here, as 2-7.

Recommendations for management:

1. Improve training of fisheries officers to achieve consistency in escapement estimates.

2. The current structure of the escapement monitoring system should be retained, but every effort should be made to improve the quality of the escapement estimates for the areas now covered.

3. The Department of Fisheries and Oceans should develop a training course in escapement counting methods that would be taken by all field staff prior to their actually doing field counts.

4. Existing work on methods of monitoring escapement should be synthesized, because many studies have not been documented, and so do not appear in the report by Cousens et al. (1982).

5. Research on the accuracy and cost of various methods for monitoring escapement should be undertaken as soon as possible.

6. Each district should attempt to maintain a high quality escapement data base on a few streams.

7. While some improvements in the escapement data base can be made through improved administration such as by providing better forms and training, increased funding will be required to raise the escapement data base to a level adequate to meet current demands.

8. The historical data base on spawning escapements of salmon should, where possible, be qualified for relative precision and accuracy, and should also be researched and documented further now, while persons associated with those historical records are still available for reference.

Recommendations for research:

1. To assess and improve techniques, agencies concerned with research and management should together pick priority stocks for which better escapement data are needed, and for which an accurate measure of system-wide escapement (e.g., by counting fences) can be obtained over a period of years. Then in different types of rivers, various techniques for measuring escapement should be applied and the data compared with those obtained by accurate measurements.

2. Analysis of life-stages should be pursued: the reasons for different survival of various life stages at different locations in the same year, or at the same locations in different years, need better understanding if the concept of indexing is to be more objectively judged as useful or useless.

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APPENDIX I

Tentative Agenda

WORKSHOP ON STREAM INDEXING FOR
SALMON ESCAPEMENT ESTIMATION
Park Royal Hotel, West Vancouver, B.C.
2-3 February 1984.

Tentative Agenda

Thursday, 2 February

9:00 a.m. - Welcome and Introduction
1. Needs for Escapement Data
   - Fisheries Management
   - Fisheries Research
   - Salmonid Enhancement Program
   - Habitat Management
   - Environmental Impact Assessment

10:30 - Coffee Break

10:45 2. Factors Affecting Escapement
   - Commercial Fishery
   - Indian Food Fishery
   - Poaching
   - Streamflow
   - Water Quality (temperature, dissolved oxygen, pollutants)

12:00 p.m. - Lunch

1:30 3. Accuracy of Existing Escapement Estimates
   - Fence Counts
   - Stream Counts (visual on foot)
   - Mark-Recapture
   - Needed Accuracy for Management

3:00 - Coffee Break

3:15 4. Stream Indexing for Escapement Estimates
   - Key or Index Streams
   - Index Stocks
   - Evidence of synchronous year-to-year fluctuations of escapement in streams of a given area in B.C.?
   - Experience in Washington State, Oregon and Alaska

6:00 - 7:00 p.m. - Happy Hour

Friday, 3 February

9:00 a.m. - Stream Indexing (cont'd)

10:30 - Coffee Break

10:45 5. Stock - Recruitment Relationships
- Identification of Stocks
  - from Escapement Data
  - by Other Techniques
- Catch Data. How accurate are they?
- Effects of Poaching
- Effects of Indian Food Fishery
- Factors Affecting Recruitment
  - Escapement
  - Egg-to-Fry Survival
  - Stream and Lake Survival of Fry and Smolts
- Early Sea-life Survival of Juveniles
- Stock - Recruitment Models

12:00 p.m. - Lunch

1:30 6. Approaches to Improvement of Existing Escapement Enumeration
- Standardization of Methods
- Intercalibration Against an Accurate Reference Method (e.g., Fence Count)
- Training

3:00 - Coffee Break

3:15 7. Summation
Recommendations

APPENDIX II

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APPENDIX III

Documents

List of Papers Submitted for the Proceedings of the Workshop on Stream Indexing for Salmon Escapement Estimation:

(Classified roughly by subject matter as follows: General; Case Studies; Modelling)

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TOWARDS DEFINITION OF THE U.I.E. (UNIVERSAL ESCAPEMENT INDEX)

by

Robert A. Bams

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Towards definition of the U.E.I. (Universal Escapement Index)

by Robert A. Bams
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I. What is Escapement?

There is much imprecise definition of what is meant by Escapement, and confusion reigns when one attempts to deal with escapement data from different sources. It seems that clarification is needed of what needs measuring before deciding how to do it. Different needs are likely to require different measurements, with different levels of accuracy and precision. One single measurement is unlikely to satisfy all needs.

The simplest working concept is stated by Total run (or Return) = Catch + Escapement (R=C+E), where C is the combined saltwater catch (gill + troll + sport). It may include values for a near (or in) river mouth mop-up fishery in cases where such terminal fisheries are extensive and controlled. This E is the fishery managers' E and is concerned with providing adequate escapements to rivers. It presupposes knowledge of the relationship between escapement target and subsequent egg deposition, which will vary greatly from system to system (see below).

The escapement, E, once in the river, will be modified by variables such as: 1) further human predation (Indian food and sport fishery, poaching, DFO egg-takes); 2) non-human predation (seals, bears); 3) other mortality, (high temperature, low DO, high flow, barriers) incurred during ascension and holding. At the end of all this we reach a spawning population, P, obviously always a proportion of E, equal to or less than 1.0. The proportion may approach 1.0 for remote chum populations in short coastal streams, but may dip well below 0.5 in other types of streams. Georgia Strait coho are believed to experience P's of 0.63 E, Georgia Strait chinook have P = 0.32 E. (Argue et al. 1983. These values include a terminal fishery component.) Along this continuum "escapement estimates" are made anywhere between E (counting weir at river mouth), via somewhere in between (fishway into lake), to on the grounds (at P, the usual FO spawning surveys). These various estimates clearly should not be labelled identically.

To complicate matters further, there is no reason to suppose that the relation between E and P is constant for any one system among years, or at different levels of abundance, nor that it covaries among even adjacent streams. All this results in increased variability, which has serious consequences for the ultimate level of precision achievable with any technique. Where measurement is critical, its location may become very important: e.g., numbers of fish on the spawning ground are not a good estimator of ocean survival.

The spawning population, P, is close to a real measure of recruitment for the next generation, but is modified by two additional variables before we arrive at the real starting point of the next cycle, the number of fertilized eggs deposited, D. These factors are: 1) fecundity and sex ratio (determines eggs per remaining spawner); and 2) deposition success (as influenced by gravel quality and quantity, water levels, fish density).

Again, these factors must vary within and among streams, further hampering the search for the universal escapement index. Presumably, an accurate determination of D is of far greater importance than one of E to the manager in charge of optimizing the natural production of a system, or to the area manager interested in predicting the strength of the next generation.

II. Who needs Escapement information?

Clearly, different people need different statistics and require different levels of accuracy and precision. The real-time management of fisheries and monitoring of spawning populations often are coarse-grain and may need nothing more than spot indices to function adequately.

Evaluation programs (especially concerning ocean survival) require far greater detail, often requiring resolutions of ±50% or even ± 10% to be useful. Given the known (or expected variabilities in estimating the various C's, E's, and P's, such programs are better served with a different approach, i.e., designs with built-in controls that allow valid assessments of relative performance at different times, locations, and levels of recovery. Absolute performance is likely to get lost in annual variability.

Stock-recruitment calculations and predictions clearly need good information on both ends of the cycle. Total returns per stock are needed for which information of comparable accuracy is needed on catch and escapement. Estimation of E is required here, not P. There is no point in estimating E with greater accuracy than can be achieved on C. Argue et al. propose improved sport catch data as well as improved escapement estimates on certain selected streams. For predictive purposes, recruitment should be estimated as late in the life-cycle as possible: D is better than P, is better than E, but even later estimates may be desirable (see below). Again, Argue et al. (1983) recognized the need to evaluate fry outputs to saturate freshwater rearing areas in their Georgia Strait study.

It is important to pre-determine if a universal escapement index can be established that will be of value to the various uses it might be put to, and, if so, if one level of accuracy and precision can satisfy all needs reasonably.

III. Alternatives to a universal escapement index.

One U.E.I., or several regional ones, may prove elusive, too expensive, or impractical. In any event, alternatives may prove viable, at least for certain applications, and should be considered at this planning stage. From my limited view point I'll hazard the following:

1. In stock management of the fisheries, improved stock-ID and estimation of stock strength and catch rates may suffice to control E's adequately in many locations.

2. Most evaluation programs of enhancement techniques or facilities are likely to be better served with built-in comparisons measuring

effectiveness on a relative level. It removes among-systems and among-years variability.

3. Field operatives may be quite well served with a somewhat improved (and standardized) estimation of P on most stock-bearing streams. It may prove feasible to estimate mortality factors at either side of P and arrive at workable estimates of E and D.

4. To upgrade, or "calibrate", such estimates it may prove necessary to do in more detail certain key systems in various strategic locations. This could supply the necessary assurance of the validity of the coarser E and D estimates, which would help both managers and data-hungry modelers. Is this what "stream-indexing" should be all about?

5. To study stock/recruitment relationships and engage in stock strength prediction, emphasis may well be better shifted away from P, or D, to measurement of fry/smolt/near-shore migrant population strengths. Variability known to occur, for example, from potential egg deposition to emergent fry alone, both within and among streams, dwarfs variability associated with present E (or P) estimates. Fourteen to 19-year long time series of such survivals on pink and chum salmon populations in two small, coastal streams show survivals from less than one to over 20 (chum) and 30 (pink) per cent. Standard deviations may equal or exceed the means! Significant and independent variability also occurs from fry to smolt and thence to near-shore fingerling populations. To ever expect yearclass-to-yearclass relationships (such as "the Ricker curve") to be of any help in forecasting is worse than naive.

6. If, by whatever means, improved population estimates become feasible and more tightly controlled escapements become a reality, more precise knowledge of just what constitutes an optimal escapement for any system will be helpful. This will involve extended knowledge of available habitats, carrying capacity of these habitats under different scenarios of species mix and densities, and, generally, more extensive watershed management planning than now exist. Production optimization will further require the monitoring of fry and smolt production, establishing the relationships with controlling environmental factors, and evaluations of different strategies through near-shore and returning adult stages. Such different strategies may concern experimental management of entire systems, or more localized manipulations of stocks and/or habitats. The combination on one system of intensive or experimental watershed management with intensive escapement indexing activities would be a mutually advantageous liaison.

To recapitulate:

1. The term "escapement" is ambiguous and needs definition. What are we after?

2. There are different needs for a statistic loosely called, or somehow related to "escapement", each with its own desirable levels of accuracy and precision. Can some of these be related to one-another?

3. It seems unlikely that a more-or-less universal escapement index, even for a limited geographic area, could reasonably satisfy most needs. High precision estimates may be more advantageously obtained with alternative approaches, but these may be of no, or little use to other needs.

4. Stock-recruitment calculations require accurate escapement data, but for predictive purposes fry, smolt, or near-shore population estimates are likely to produce information of greater usability.

5. Upgrading and standardizing existing techniques may serve several needs adequately and, possibly, more usefully or economically. Should this be explored?

6. Stream indexing may serve a strong function in "calibrating" co-existing coarse-grained techniques and thus elevate the entire escapement data system. Is "indexing" then only a part of a necessarily interrelated set of techniques?

7. With improved information on and control of escapements, natural production can be optimized on a systems basis. Prerequisites will be increased understanding of carrying capacities of available habitats, and system responses to scenarios differing in species mix, levels of density, and combinations of environmental factors. Can such work be undertaken?

8. Intensive escapement indexing activities could be most usefully combined with experimental systems management strategies.

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STREAM INDEXING: ITS USEFULNESS AND LIMITATIONS

by

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ABSTRACT

Different uses of the term Stream Indexing are identified. Stream Indexing, as applied to escapement estimates of salmon, is reviewed from examples of current practice with pink and chum salmon in South East Alaska (Jones and Dangel 1983), with coho salmon in Oregon (Beidler and Nickelson 1980), and with sockeye salmon in Cook Inlet, Alaska (King and Tarbox 1983). The limitations of Stream Indexing are pointed out, and the need is stressed to define clearly the problem that is being addressed before deciding whether Stream Indexing could contribute to its solution.

What it is

The term Stream Indexing has been applied to several practices. Most commmonly it means the estimation of the relative abundance of salmon populations in a stream. When applied to adult fish the figure obtained is an escapement index; here, then, the term Stream Index is a misnomer and Escapement Index is more appropriate. Indexing in this sense has been practiced in Washington, Oregon and Alaska since the 1950's (Cousens et al. 1982). The assessment of relative abundance can be made on selected spawning grounds within one stream, or on spawning grounds in more than one stream. The index counts are sometimes compared to an initial carefully acquired absolute escapement estimate. This is derived from counts obtained at a fence, or a viewing tower, with some kind of counting device that records migrating fish, or by mark-recovery of adults.

Stream Indexing can also be applied to other stages of fish, e.g., eggs, fry or smolts. Finally, the term is used sometimes in a different sense, when some property of a stream (e.g. discharge) is taken as a relative measure of this property in other streams.

Stream Indexing in practice

To understand why and how Stream Indexing is used by fishery biologists it is helpful to look at current practice.

(1) Pink and chum salmon surveys in South East Alaska (Jones and Dangel 1983).

In Southeastern Alaska the Department of Fish and Game survey pink and chum salmon in selected spawning areas (i.e. index areas) in index streams. The Region is divided into 15 fisheries districts, each divided into 5 separate management areas. There are over 2,500 anadromous streams in Southeastern Alaska and the escapement survey method is by small plane, although many surveys are also conducted on foot each year. In addition a

counting weir is operated in a northern southeastern creek, in a south southeastern creek, and in 3 other creeks.

Aerial estimates of salmon abundance are made for bays, off stream mouths and in the streams themselves. For the streams, counts are made of both live and dead salmon by species. The aerial estimates are used primarily for in-season management of the purse seine fisheries. District escapement indices (sic) are calculated for pink salmon using the peak estimate for each stream. The four main management areas - Juneau, Sitka, Petersburg and Ketchikan - all use the same method for district escapement calculations:

(a) Streams are separated into "large" or "small" on the basis of the peak escapement estimate (large, over 10,000; small, less than 10,000), and the total escapement is calculated for each category.

(b) The number of streams in each category is totalled, and the sum of the two is subtracted from all the streams in the area. This gives the number of unsurveyed streams.

(c) The average escapement to the small streams is then multiplied by the number of unsurveyed streams to give an estimate of escapement to all streams not surveyed.

(d) The estimate of escapement to unsurveyed streams (c) is added to the large and small escapement totals to give the final total escapement for the area.

In addition, pre-emergent fry estimates are made in March in selected study areas of 95 streams. Hydraulic sampling is carried out to give an estimate of overwinter survival of pink and chum salmon fry. Over 5000 samples of 0.2 square meter each are collected. Each sample is chosen at random from a study area and most study areas have 35-40 digs. The samples give fry indices used for forecasting. For southern areas the fry index is the quotient of the total number of live fry and eggs divided by the area sampled in square meters. In the northern areas the indices are weighted by the relative strength of the escapement to the study streams within each brood year, further weighted by the total estimated spawning area for each district.

The results for the pink and chum salmon escapements are related to the 20-year average for each species; e.g., the overall escapement index for pink salmon in the southeast might be 5.6 million or 33% above the recent 20-year average escapement and just 0.4 million below the goal for southern Southeastern Alaska.

The escapements based on Indices are a small fraction of counts obtained by weirs; when a new weir is used on a river the counts obtained from it cannot be included in the Index counts as they would produce a misleadingly high figure.

The salmon pre-emergent fry indices are similarly related to the recent 20-year average indices for pink and chum, e.g., "the southern areas index of 89.3 fry per square meter was 10% below the recent 20-year average."

The surveys are recorded in about 230 pages of printed data.

(2) Enumeration of coho wild stocks in Oregon (Beidler and Nickelson 1980)

The Oregon Department of Fish and Wildlife enumerate salmon spawning runs using a system of standard indices. A standard index for coho is derived from a set of reaches of 11 streams totalling 23.7 km. The combined count of live and dead fish (in terms of fish/km) is used as an index to determine annual trends in abundance. The objectives of the coho survey system are to measure trends in escapement, and to measure the relative abundance of spawners in each year, especially wild fish. The desirability of having an absolute measure is recognized.

In an evaluation of the index system 4 assumptions were examined:

Assumption 1: The distribution of spawning fish within a watershed is constant, such that a consistent proportion of the run spawns in the index area each year. This assumption means that an index area is always populated in proportion to the abundance of fish in the system, and that there is no significant variability of spawning within the system. Tests of the validity of this proved to be inconclusive. It was recognized that, if the survey index units contained only choice spawning habitat, in a year of low abundance the units could hold a disproportionate amount of the run. Conversely if the index areas were of poor spawning habitat they would, in a year of low abundance, contain disproportionately few fish. Index areas, therefore, should contain both poor and good spawning habitat.

Assumption 2: The peak count of live and dead fish is consistently proportional to the size of the total run. Examination of this assumption showed that it holds only roughly, or not at all. In one test, peak counts of one creek were compared with total trap counts in a nearby creek. There proved to be little correlation. Peak counts are a poor indicator of abundance on a year-to-year basis. For this reason it is recommended that peak counts be replaced by estimates based on an "area under the curve," i.e. numbers of observed live fish are plotted over time, with zero values added 7 days before the first and after the last observations to close the curve. The area under the curve is calculated to give the number of fish-days on the index area. When this is divided by the average time (11 days) coho live on the grounds it gives an estimate of the number of fish. It is yet to be demonstrated, however, that the area under the curve method is in fact superior to the peak count method.

Assumption 3: The efficiency of the index counts is consistent between surveys and years. This assumption appears to be valid.

Assumption 4: The probability of observing a given fish is constant for all levels of abundance. The assumption could not be validated. There seems to be a likelihood that the index counts are less reliable at lower levels of abundance.

An increase in the number of surveys from 11 to 40 would improve the precision of the estimates from about ±72% of the mean to ±32%, provided that the 4 assumptions are valid. Since this is not so, this calculation can serve only as a guideline.

It is concluded that the most significant improvement in estimates would come from making observations at regular intervals throughout the entire run of the fish. Changes in water conditions, however, and in the behaviour of the fish in relation to their maturity, will always be sources of error in observations.

(3) Sockeye salmon escapements in Cook Inlet, Alaska (King and Tarbox 1983)

Since the early 1960's the Alaska Department of Fish and Game has contracted the Bendix Corporation to count sockeye salmon migrating to the spawning grounds in the major rivers of the Cook Inlet area of Alaska. Glacial silt in these rivers severely limits visual means of escapement assessment. Bendix side-scanning sonar counters have been installed in 4 rivers, and 2 units (one per bank) have been operated in each since 1980.

The objectives in 1982 were to estimate:

(a) the relative magnitude of escapement and migration timing of sockeye in the mainstem rivers;

(b) the age, length, sex and scale characteristics of the sockeye salmon escapement; and

(c) the magnitude, timing and distribution of adult sockeye salmon within established index areas.

Fishwheels were installed to assess migration timing, and relative abundance of salmon species, provide relative abundance data for apportionment of sonar counts, and obtain samples of age, length, weight and sex composition. Index-area escapement surveys were conducted on the main rivers and various minor river systems. A combination of helicopter, fixed wing aircraft, and foot surveys was conducted from August 1 to mid-September. These are made annually to obtain an indication of spawner distribution and relative escapement magnitude within tributaries.

In presenting their results the authors show that the effectiveness of sonar counters varies greatly from one river to another, depending on river conditions. "Sockeye salmon sonar counts appear to be a relatively accurate measure of escapement within the Kenai River drainage. The magnitude of the run (more than 600,000 fish) and short duration of entry are ideal for counting with the Bendix system. In addition, the shore-oriented migratory behaviour of the late run probably results in most fish moving through the hydroacoustic beam. Finally, it is felt that only limited sockeye spawning occurs below the sonar site." The count obtained is compared to the average escapement of the 4 previous years, as are data from index-area surveys.

In contrast "the accuracy of Kasilof River sockeye salmon escapement estimates has been suspect due to apparent offshore migration at

the sonar site in previous years. To date, efforts made to quantify the magnitude of mid-river migration to assess the extent of undercounting have been unsuccessful. Data from other Cook Inlet sockeye salmon sonar counting operations have indicated a definite inshore migration tendency in glacial systems but suggest that water velocity and bottom topography influence fish behaviour and consequently the manner in which fish migrate over the sonar substrate."

Where such doubts arise, and where mixed species, with differences in migratory behaviour, lead to questions concerning the apportionment of counts, then the escapement estimates are viewed as a measure of relative rather than absolute abundance.

The Limits of Stream Indexing

Indices of population size are commonly used in the estimation of animal populations, especially for insects (Southwood 1978), as they allow comparisons to be made in time and space. There is no clear distinction between relative and absolute methods, for relative methods can be calibrated to give absolute numbers, and absolute methods may not be 100% efficient. The estimation of absolute population by relative methods is difficult, however; what is really being estimated is a proportion of the members of a population that is susceptible to some form of sampling process. Some kinds of error in estimation therefore occur. In Stream Indexing this error is presumably always in one direction i.e. too few fish may be counted, rarely too many. The physical characteristics of a site (e.g. discharge, colour of water, amount of debris) will determine how close indices may be to absolute numbers. In general, the data from relative methods should be used and interpreted with far more caution than is customary. Comparisons of different species in different stream habitats are particularly open to error.

One of the most powerful approaches to estimating animal populations is to have two, three or even more different methods of estimation, employing different assumptions. If the results prove to be of the same order of magnitude this is more valuable than having fiducial limits on one method whose bias may be obscure. In estimating escapements, however, completely independent methods are rarely pursued. A series of independent indices can be compared with actual population estimates. If the ratio of one to the other is fairly constant then the reliability of the indices is confirmed and they may be used for comparative purposes. Such indices, however, are not of use for assessing survival of life-stages. Here absolute estimates are necessary.

It is apparent from the above that the first question to ask before estimating a population is: For what purpose are the estimates intended? For many every-day management purposes relative estimates may be adequate. They may not be ideal, but improvements in accuracy may not justify the increase in costs in terms of labour and time. A fishery officer who visits 5 streams every year between two dates may be able to detect annual differences in escapements of fish that are both sufficient for his purposes and scientifically sound. On the other hand such estimates may be valueless for assessing whether there is a 50% increase in returns following an

enhancement operation. For such work the full technology required for absolute counts may be necessary.

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CAN STREAM INDEXING IMPROVE SALMON ESCAPEMENT ESTIMATES?

by

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INTRODUCTION

Estimates of spawner abundance on the spawning beds (escapement) along with the catch attributable to a stream or area are the major indices fisheries managers use to assess the status of salmon stocks. However, the quality of escapement estimates is often criticized on two points: 1) spawning stocks are rarely measured without considerable error, and 2) usually only a limited number of observations are available (Walters and Ludwig 1981, Ludwig and Walters 1981). The usefulness of escapement estimates has consequently often been questioned. Because escapement estimates require considerable expense and effort to acquire, some managers have further argued that if existing stock assessments are not used in the management process, then they are a wasteful and inefficient activity (Sprout 1984).

New, consistent techniques to provide equal or better quality assessments at less cost have been advocated (Pearse 1982). Stream indexing is one new method under development which may meet these goals. The strategy of this technique is to assess fewer stocks more accurately, then predict the status of the unassessed stocks from the measured stock, thus both improving the quality of the assessments and reducing the total effort (cost) required to acquire them. To work, indexing requires both that the performance of the index stock must be proportionately constant relative to the unassessed stocks, and if the assessed and unassessed stocks are unequal, the index stock must be initially calibrated to the unassessed stocks (i.e. all stocks must be assessed initially). Therefore, for indexing to be a practical alternative to current methods, groups of stocks with similar performance must commonly exist.

The purpose of this paper is to analyze an existing set of escapement estimates for two attributes:

1) evidence of performance common to groups of salmon populations; and
2) inferences useful for the management of the stocks despite the errors likely present in the escapement estimates.

THE DATA SET

The escapement estimates used for this analysis are for streams on the Queen Charlotte Islands, Statistical Areas 1, 2E, and 2W. There are 265 streams on the Queen Charlotte Islands which probably contain salmon. Of these, 165 have annual escapement records beginning in 1947, or in a few instances, 1967. These estimates have been summarized by statistical area up to 1978 (Marshall et al. 1978a, Marshall et al. 1978b, Brown and Musgrave 1979). For this analysis these records have been extended up to 1982 by acquiring the escapement estimates from the "Annual salmon stream and spawning ground reports" compiled by the fishery officers responsible for each stream.

These 165 streams are distributed in three physiographic regions which are similar within the regions but have distinct differences between the regions (Fig. 1). The Queen Charlotte Ranges are characterized by steep, mountainous terrain with high rainfall, while the Skidegate Plateau and Charlotte Lowlands to the east are elevated extensions of Hecate Strait, respectively characterized by rolling forested hills and boggy lowlands. Land use within the regions is similarly segregated because of the topography with forestry and mining occurring mostly on the Skidegate Plateau and Queen Charlotte Ranges, and agriculture occurring on the Charlotte Lowlands. Together the topography, climate, and land use of the physiographic regions provide a natural grouping of similar streams on the Queen Charlotte Islands.

The performance of several salmon populations should be expected to be similar only if they share a habitat base and management history common to the group. Because the physiographic regions approximate the statistical areas (Fig. 1), and these salmon stocks have been both managed and their escapement estimates summarized on these statistical boundaries, their escapements provide a good opportunity to assess the principles of stream indexing.

THE HABITAT BASE

Because the production of salmon stocks is a function of the inherent productivity of the environment supporting them, the relative quantity and quality of habitat available in each statistical area were estimated by measuring the drainage area and usable stream length of each stream. The drainage area was calculated from 1:50,000 topographic maps using a graphics tablet on an Apple 11+ computer. The length of stream used by each species was taken from notes of the fishery officers on the escapement reports. Where no distribution limits were given, the length of stream usable by salmon was measured from the same maps, with their upstream distribution assumed to terminate at a mean gradient of 3%. Where impassable barriers occurred before 3% gradient, useable length was assumed to terminate there; where 3% gradient was never reached, useable length was assumed to terminate at the end of a permanent watercourse as indicated on the maps.

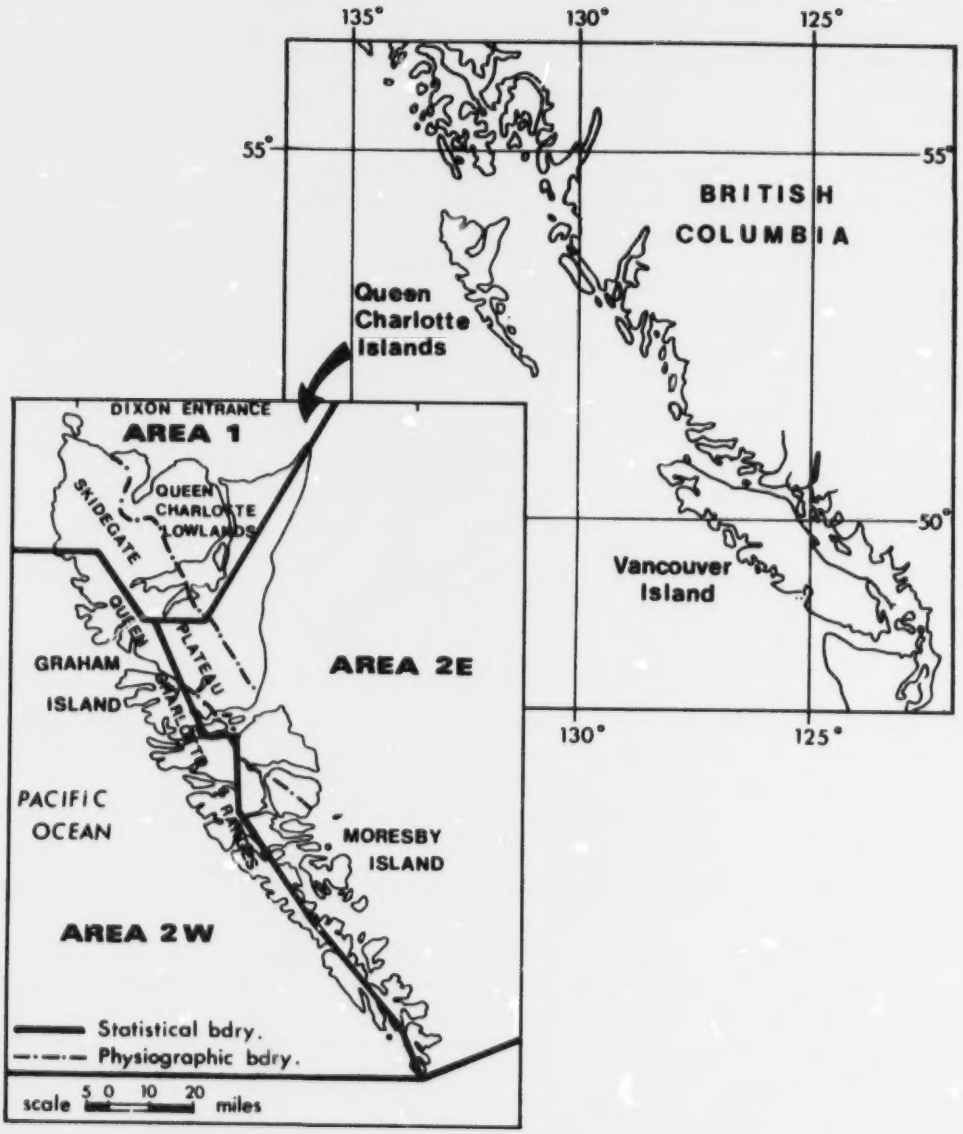

Figure 1. Map of the Queen Charlotte Islands showing the relationship between the statistical areas and the physiographic regions.

Based on this rough assessment, clear differences between the type and amount of habitat available in each statistical area emerged. As expected from the topography, statistical area 1 has relatively large drainage areas, while areas 2E and 2W have drainage areas smaller than the mean (Table 1). A relationship not so apparent is that on the Queen Charlotte Islands at least, sockeye salmon occupy rivers in large watersheds, chum salmon occupy rivers in small watersheds, and coho and pink salmon occupy rivers with watersheds near the average size. (Chinook salmon are excluded from this analysis because of their limited distribution on the Queen Charlotte Islands. They occur only in two rivers, both in statistical area 1.) An important consequence of this relationship between drainage size and species affinity is that the different statistical areas appear to have habitat best suited to produce different species: area 1 is most suitable for sockeye, areas 2E and 2W are most suitable for chum, and all areas are equally suitable for coho and pink salmon.

In addition to species potential, a second difference between the stocks of the statistical areas resulting from their respective habitat differences, is difference in their species diversity. Large watersheds have the greatest species diversity; consequently, area 1 to area 2W have progressively less complex salmon communities (mean species diversity area 1 = 3.33, area 2E = 2.85, area 2W = 2.59).

$$\text{Species diversity} = 1.92 + 0.59\ (\text{Log drainage area } [\text{km}^2])$$

An important point from this regression is that even the smallest watersheds should have at least two salmon species, but several streams in areas 2E and 2W now support only one species (Appendix Table 1).

PRODUCTION

Current relative production from each statistical area was estimated by:

$$\text{Mean production km}^{-1} = \text{mean escapement km}^{-1} \times (1 - \text{exploitation rate})$$

(Production here is equated to recruitment to the fishery and assumes similar marine survival for all populations.) Current escapement estimates used are the mean escapements for the years 1974-77, 79, and 81-82 divided by the total number of kilometers used by that species in each statistical area. (No escapement estimates were made in 1978 or 1980.) These escapements per kilometer of stream are:

	Statistical Area 1	Statistical Area 2E	Statistical Area 2W
Coho	254	138	9
Pink	1236	1373	530
Chum	859	957	623
Sockeye	233	137	285

TABLE 1 Mean drainage size (km^2) of streams inhabitated by the different Pacific salmon species on the Queen Charlotte Islands. The number of populations are in parentheses.

Species	Statistical Area 1	Statistical Area 2E	Statistical Area 2W	$\bar{X}$ (total n)
Coho	141(15)	18(76)	20(28)	34(119)
Pink	141(15)	19(67)	21(38)	35(120)
Chum	145(11)	12(82)	12(55)	22(148)
Sockeye	233(6)	62(7)	26(3)	119(16)
$\bar{X}$ (total n)	154(47)	17(232)	17(124)	33(403)

Mean exploitation rates used in the calculation of production were taken from Wong (1982). The mean rates for the years 1975 to 1979 are:

	Statistical Area 1	Statistical Area 2E	Statistical Area 2W
Coho	0.51	0.52	0.52
Pink (even yr)	0.13	0.60	0.60
Chum	0.10	0.34	0.34
Sockeye	0.30	0.40	0.40

The production calculations confirm that the Queen Charlotte Islands produce mostly pink and chum salmon, but contrary to common perception and historical escapements, streams in statistical area 2E are producing most of these fish, both in total and per kilometer production, not streams in area 1 (Table 2). By comparing production to habitat availability for each species in each area, it becomes clear not only which statistical area has the best habitat for a particular species, but also which area has the worst habitat for that species. For example, area 1 streams are the best coho salmon producers; area 2W streams are the worst coho salmon producers.

Ratio of production (%) to habitat availability (%)

	Statistical Area 1	Statistical Area 2E	Statistical Area 2W
Coho	1.55	0.86	0.05
Pink	0.63	1.50	0.58
Chum	0.80	1.21	0.79
Sockeye	1.09	0.75	1.51

These ratios can also be calculated as:

$$\frac{\textit{mean number of adults of species X produced per kilometer in area 1}}{\textit{mean number of adults of species X produced per kilometer in QCI}}$$

Because the production calculations (Table 2) are forced to assume that the exploitation rates are constant over the time period of the escapement records (an unreasonable assumption), any changes in total escapements over time appear to have resulted from changes in the productive capacity of the habitat. For example, the decline in pink salmon escapements in area 1 (Fig. 2a, 2c) by inference have been caused not by fishing but by changes in the habitat and land use in statistical area 1. Regardless of whether fishing or habitat changes have caused area 1 to shift from pink salmon to coho salmon production, the significance of the shift for stream indexing is that the best species for indexing within a particular area may change over time.

TABLE 2 Mean annual[1] salmon production[2] per kilometer of stream for the Queen Charlotte Islands by species and region. The amount of habitat[3] is in parentheses.

Species	Statistical Area 1	Statistical Area 2E	Statistical Area 2W	$\bar{X}$ production (total habitat)
Coho	518(248)	288(263)	18(107)	334(618)
Pink	1421(86)	3432(133)	1324(84)	2277(303)
Chum	955(56)	1450(131)	944(80)	1195(267)
Sockeye	332(120)	228(62)	474(9)	305(191)
$\bar{X}$ production	674	1250	689	924

[1] Based on the years 1974-77, 79, and 81-82. No escapement estimates were made in 1978 or 1980.

[2] Adults returning to the streams in the statistical area, calculated by mean escapement per km X (1 - exploitation rate).

[3] kilometers of stream used by that species.

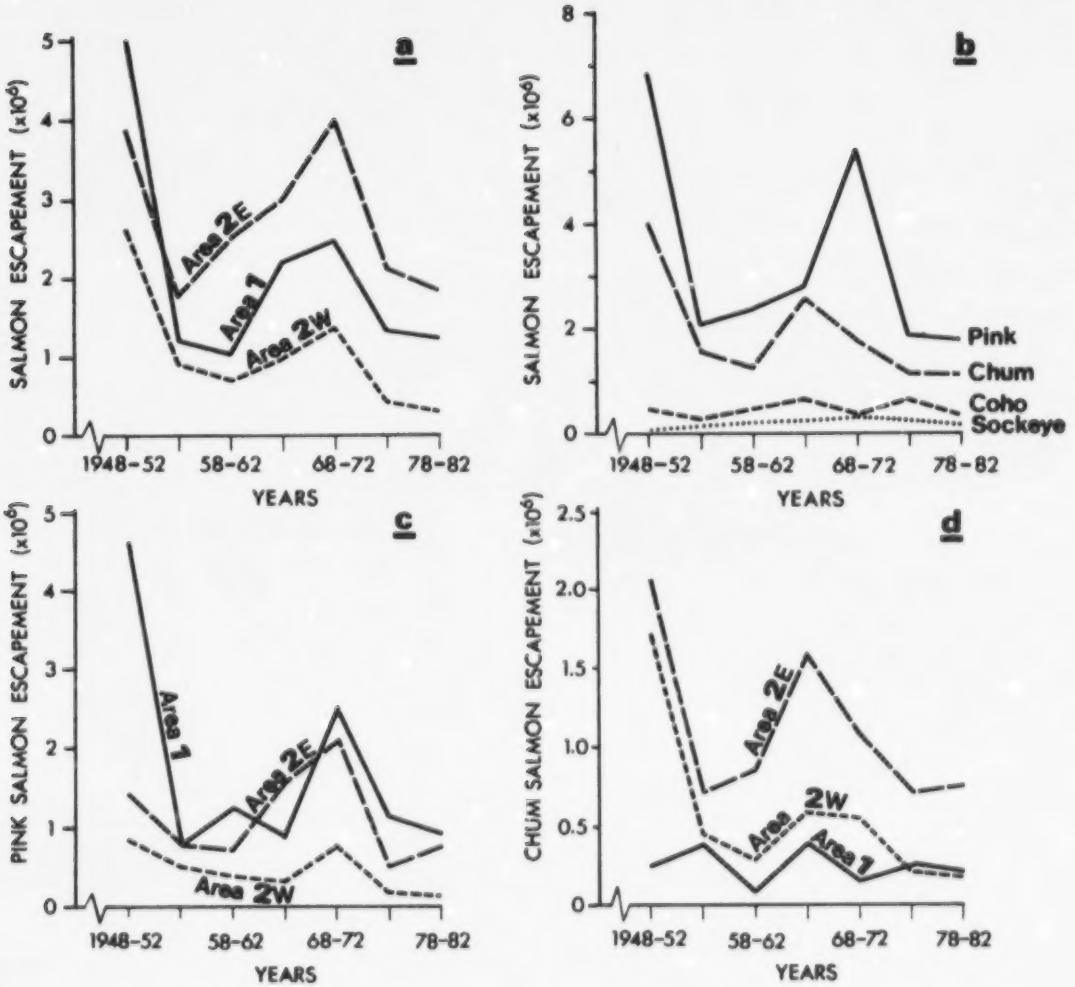

Figure 2. Decline in the Queen Charlotte Islands salmon escapements from 1948 to the present. a Similarity in trends among statistical areas 1, 2E, and 2W. b Pink and chum salmon declined while coho and sockeye salmon remained stable. c Most of the pink salmon decline occurred in area 1. d Most of the chum salmon decline occurred in areas 2E and 2W. Points are the totals for five-year intervals on all panels.

DECLINING ESCAPEMENTS

Escapements on the Queen Charlotte Islands have declined substantially from when records began being kept. Today's escapements are only one-third of the escapements at the beginning of the record (total for 1948-52 = 11.5 X 10^6 versus total for 1978-82 = 3.4 X 10^6). This decline has occurred equally in all three statistical areas (Fig. 2a), but it has not occurred equally in all species, or in the same species in each area. Most of the decline has occurred to pink and chum stocks (Fig. 2b), with most of the decline in pink stocks occurring in area 1 (Fig. 2c) and chum stocks in areas 2E and 2W (Fig. 2d).

These species - and area - specific differences have important significance for stream indexing because they demonstrate the existence of stream and stock variability within the statistical groups. In the Queen Charlotte Island streams therefore, the status of one species in one area may be neither representative of the same species in a different area, nor a different species in the same area. The pattern of escapements in Figure 2 does, however, support the basic premise of indexing - that one species may be representative of other populations of the same species in the same area.

Generally, the decline in Queen Charlotte Island stocks has occurred through fewer fish returning to the same number of streams, but there have also been the extinctions of some populations. (Extinction is defined as no recorded escapement or evidence of fish present [N/O and UNK, respectively, in the escapement records] for 10 consecutive years.) Twenty-nine populations have become extinct since records began being kept (6% of the total for all Queen Charlotte Islands). Again these extinctions have not occurred equally either between the statistical areas or the species. Most of the extinctions have been coho and pink salmon populations in areas 2E and 2W (Appendix Table 2):

	Statistical Area 1	Statistical Area 2E	Statistical Area 2W
	Sockeye 1	Pink 5	Pink 8
		Coho 4	Coho 7
		Chum 2	Chum 2
Total	1	11	17

These extinctions have been increasing each year since 1958 to where the mean annual extinction rate is now four populations per year. These extinctions combined with generally declining escapements have three important consequences for the Queen Charlotte Island salmon stocks:

1) Stock vulnerability has increased. Extinctions have left many streams in areas 2E and 2W only producing a single salmon species. Even the smallest watersheds should support at least two salmon species. Reduced faunal diversity decreases ecosystem resistance to stress.

2) Some streams could become barren. The mean "extinction" escapements (the last recorded escapement before extinction) for each species are:

		Total escapements per river		Escapements per kilometer	
Coho	n=12	$\bar{X}$= 99	SD=114	$\bar{X}$= 93	SD=100
Pink	n=12	$\bar{X}$=406	SD=312	$\bar{X}$=492	SD=371
Chum	n= 4	$\bar{X}$=193	SD=188	$\bar{X}$=143	SD=141
Sockeye	n= 1	$\bar{X}$= 25	SD= 0	$\bar{X}$= 4	SD= 0

Comparison of the current escapements (1974-1982) in Table 2 with these "extinction" escapements reveals that all coho populations and many pink salmon populations in area 2W are currently escaping below these extinction escapements. This does not mean that these populations will become extinct, but that they are extremely vulnerable to any catastrophic habitat or management stress in the future. Extinctions will continue to occur and some streams may become barren like Douglas Inlet Creek which in 1952 had maximum escapements of 7500 fish of three species.

3) Catches will be mostly chum salmon. Extinctions are changing chum-coho-pink salmon producing streams into chum salmon producers (Appendix Table 1). Chum salmon apparently are somehow more resistant than the other species to selective pressures that have occurred in the past, so that if the trends continue, chum salmon will ultimately dominate the salmon fauna of statistical areas 2E and 2W.

DISCUSSION

Stream indexing shows some potential for improving escapement estimates. The escapement estimates for salmon streams on the Queen Charlotte Islands show some evidence of common performance within statistical areas (Table 3). While this supports the premise on which stream indexing is based, analysis of these escapements clearly indicate certain constraints under which indexing may be a valid technique.

1) Index and indexed stocks must come from homogeneous environments. While it is unclear whether management or environmental differences are causing the differences in the performance of the stocks between the statistical areas, it is clear that there is less variance within

TABLE 3 Status of Queen Charlotte Islands salmon streams and stocks.

	Statistical Area 1	Statistical Area 2E	Statistical Area 2W
Number of streams	15	86	64
Mean drainage area per stream km^2 (SD)	140(131)	16(41)	15(18)
Mean stream length used by salmon km (SD)	16.5(17.8)	3.1(6.1)	2.3(2.9)
Total amount of salmon habitat (km)	248	267	147
Species diversity (mean no. species per stream)	3.33	2.85	2.59
Number of single-species streams (% of area streams)	0(0)	11(13)	19(30)
Number of populations lost since 1948 (% of area populations)	1(2.0)	11(4.6)	17(10.3)

statistical areas than between statistical areas. Careful selection of where the group boundaries lie is therefore important. This variation will determine the extent of extrapolation possible from the index stream.

The relationships found in this analysis may have been improved had the streams been regrouped to reflect the physiographic boundaries (Fig. 1 [i.e. reflect a habitat bias]). The use of the statistical boundaries resulted in a management-effect bias in the analysis - an approach which is correct only if exploitation rather than habitat has had the greater impact on current stock status.

2) The species which gives the best results with indexing in one area may be different in another area or in the same area at a later time. The predictions based on an index stream, therefore, would be more valid for one species than for others, and this relative validity could change with changing selective pressures. Periodic validation would be required, and in statistical areas 2E and 2W extinctions could compromise the effectiveness of the technique.

3) Stream indexing may be limited only to accurate predictions of trends rather than day to day escapements. Stream indexing requires that the performance of the index stock must be proportionally constant to the unassessed stocks. However, because random variation can occur in this proportion for abundance, growth, survival, recruitment, etc. for individual stocks or drainage areas due to specific habitat or management events, day-to-day indexing during a fishery may not be possible.

Existing escapement estimates are useful despite their inherent errors. By considering only the presence or absence of species, rather than their relative or absolute abundance, new and useful information including extinctions, future vulnerability, likely streams for enhancement, and relative productive capacity of the environment was derived. If the escapement reports are correct, then these conclusions are inescapable even without the magnitude of escapement being accurate. Stream indexing could have provided improved precision in the escapement estimates but without astute application it may simply trade one set of uncertainties in the inferences for another.

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APPENDIX TABLE 1 Species-diversity history and recent[1] escapements to single-species salmon streams on the Queen Charlotte Islands.

Statistical Area	Current species	Historical species[2]	Date[3]	River	Drainage area (km^2)	Mean annual escapement
2E	Chum		BOR[4]	Burnaby Narrows 1st R.H.	2.6	194
	Chum		BOR	Burnaby Narrows 2nd R.H.	2.6	109
	Chum		BOR	Carmichael Ck.	9.2	222
	Chum		BOR	Fanny Ck.	5.1	100
	Chum		BOR	Pool Inlet Ck. L.H.	1.0	812
	Chum		BOR	Takelley Ck.	2.0	16
	Coho		BOR	Jungle Ck.	18.2	189
	Chum	Ch, Co	1970	Marker Ck.	1.3	207
	Chum	Ch, Co, Pk	1970	Sewell Inlet Ck. 2nd L.H.	1.3	1
	Chum	Ch, Co	1974	Moody Ck.	1.8	71
	Coho	Co, Ch, Pk	1974	Gray Bay Ck.	5.6	146
2W	Chum		BOR	Coates Ck.	83.2	100
	Chum		BOR	Douglas Inlet Ck. R.H.	3.1	50
	Chum		BOR	Edwards	10.5	10
	Chum		BOR	Goski Bay Ck.	11.3	729
	Chum		BOR	Mudge Ck.	1.8	100
	Chum		BOR	Nesto Inlet Ck. inner	3.8	1850
	Chum		BOR	Nesto Inlet Ck. outer	3.6	3
	Chum		BOR	Port Louis Ck. outer	5.6	54
	Chum		BOR	Shields Ck.	3.8	6
	Chum		BOR	Sperm Bay Ck.	1.5	229
	Chum		BOR	Steel Ck.	2.3	1329
	Chum		BOR	Yakulanas Ck.	2.6	1307
	Pink		BOR	Cone Head	5.1	1095
	Chum	Ch, Co	1958	Clapp Basin Ck.	4.4	241
	Chum	Ch, Co, Pk	1966	Staki Ck.	1.8	1039
	Chum	Ch, Co, Pk	1968	Flamingo Inlet Ck.	5.1	4564
	Chum	Ch, Co, Pk	1970	Rennell Ck.	9.0	184
	Chum	Ch, Co, Pk	1972	Indian Bay Ck.	2.0	17

[1] Based on the years 1974-77, 79, and 81-82. No escapement estimates were made in 1978 or 1980.

[2] Ch = chum, Co = coho, Pk = pink.

[3] The date when the stream became single-species. Where single-species status has arisen through extinction (S), populations have been deemed extinct only after 10 consecutive years of no recorded escapement or evidence of fish present.

[4] Beginning of record (usually 1947). These streams have always been single-species.

APPENDIX TABLE 2 Salmon populations on the Queen Charlotte Islands which have become extinct[1] since 1947.

Statistical Area	Date	Species	River	Drainage area (km^2)	Length useable (km)	Extinction escapement[2] total	Extinction escapement[2] per km
1	1962	Sockeye	Datlamen Ck.	61.4	7.2	25	3.5
2E	1966	Pink	Collision Bay Ck.	3.6	0.8	400	500
	1970	Chum	Breaker Bay Ck.	14.6	1.8	400	222
	1970	Pink	Sewell Inlet Ck. 2nd L.H.	1.3	0.8	750	938
	1970	Coho	Dass Ck.	2.8	0.4	25	63
	1970	Coho	Marker Ck.	1.3	0.8	25	32
	1970	Coho	Sewell Inlet Ck. 2nd L.H.	1.3	0.8	200	250
	1974	Pink	Gray Bay Ck.	5.6	1.0	150	150
	1974	Pink	Ikeda Ck.	3.8	1.5	25	17
	1974	Pink	Skaat Harbor Ck.	4.6	1.2	1000	833
	1974	Coho	Moody Ck.	1.8	1.2	400	333
	1974	Chum	Gray Bay Ck.	5.6	1.0	300	300
2W	1951	Coho	Indian Bay Ck.	2.1	0.2	50	250
	1952	Coho	Rennell Ck.	8.9	0.8	75	94
	1958	Coho	Clapp Basin Ck.	4.4	1.6	25	16
	1958	Chum	Riley Ck.	27.7	4.8	50	10
	1962	Coho	Douglas Inlet Ck.	3.1	0.5	50	100
	1962	Pink	Douglas Inlet Ck.	3.1	0.5	200	400
	1965	Coho	Boomchain Bay Ck.	18.7	4.0	50	13
	1966	Coho	Staki Ck.	1.8	0.8	50	63
	1966	Pink	Staki Ck.	1.8	0.8	700	875
	1967	Coho	Inskip Ck.	13.3	1.6	200	125
	1968	Coho	Flamingo Inlet Ck.	5.1	1.6	40	25
	1968	Coho	North Arm Ck. R.H.	1.8	0.8	25	32
	1968	Pink	Buck Channel Ck.	1.5	0.5	500	1000
	1968[3]	Pink	Flamingo Inlet Ck.	5.1	1.6	400	250
	1969[3]	Chum	Douglas Inlet Ck.	3.1	0.5	20	40
	1970	Pink	Rennell Ck.	8.9	0.8	50	63
	1972	Coho	Bottle Inlet Ck.	8.2	1.6	100	63
	1972	Pink	Indian Bay Ck.	2.1	0.2	200	1000
	1973	Pink	Mountain Ck.	13.1	0.8	100	125
	1974	Pink	Gold Harbour Ck.	2.6	0.8	600	750

[1] No recorded escapement or evidence of fish present (N/O and UNK, respectively, in the escapement records) for 10 consecutive years.

[2] The last recorded escapement.

[3] Now barren.

STREAM INDEXING FOR SALMON ESCAPEMENT ESTIMATION IN BRITISH COLUMBIA: A PROPOSAL FOR A PILOT STUDY

by

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ABSTRACT

A proposal is described for testing the hypothesis that an "index stream" can represent other streams in the same drainage basin or biogeoclimatic zone in British Columbia, in terms of spawning salmon escapement. Such conditions as a mixed-stock fishery and unreliable catch data are considered to be factors that can confound the experiment, and a careful selection of the study site has to be made to avoid these obstacles. A pilot area with about 6 streams is proposed for a 15-year study, which would include escapement enumeration, smolt counts, egg-to-fry survival tests and other biotic and abiotic investigations. Among the abiotic factors, streamflow, turbidity/suspended solids, temperature and pH are considered most important. Other biological observations should include stream invertebrates, which are regarded a vital food source for salmon juveniles. A major objective of the study will be to improve the accuracy and precision of salmon escapement data in British Columbia for management of the salmonid resources.

STREAM INDEXING FOR SALMON ESCAPEMENT ESTIMATION IN BRITISH COLUMBIA: A PROPOSAL FOR A PILOT STUDY

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1. INTRODUCTION

The concept of "index streams" is not new in British Columbia. The idea of a network of "key streams" (considered here as synonymous with "index streams"), for salmon research and management dates back to the late 1940's and early '50's. In a letter, dated 9 August 1950, from Mr. A. J. Whitmore, then Chief Supervisor of Fisheries for the Department of Fisheries in the Pacific Region, to Dr. J. L. Hart, Director of the Pacific Biological Station, Nanaimo, B. C., a list of 117 streams, prepared by the three regional supervisors, was submitted as potential key streams in the province (Whitmore 1950). It was proposed that these streams were to be "given special attention in the matter of detailed observations as to the spawning of several varieties of salmon and subsequent developing stream conditions in relation to survival and development of the hatch. --- this coverage was to be additional to the annual spawning survey and report by the fishery officers; the selected streams which perhaps would be regarded as representative of these generally in the particular subdistrict, would be visited at regular intervals and special details of observations would be recorded for the particular purpose of the over-all salmon surveys and studies being conducted by biological officers from your Station".

Subsequently, D. R. Foskett (1950) of the Pacific Biological Station carried out a reconnaissance for key streams on Vancouver Island and prepared a list of 39 streams proposed for a key stream network. W. P. Wickett, of the same establishment, also conducted early surveys for key streams on Vancouver Island and on the lower mainland of British Columbia (W. P. Wickett, personal communication). It is not clear from the records how far the concept of key streams was pursued in both salmon management at the Department of Fisheries in Vancouver and in research at the Pacific Biological Station in Nanaimo. From Annual Reports and publications of the Station it is obvious that research moved in the direction of studies

of particular species at a number of specific locations in the province: (1) sockeye salmon in Babine and Lakelse lakes, contributing to the Skeena River fishery; (2) pink and chum salmon in Hooknose Creek and Port John Lake in order to elucidate their juvenile behaviour, survival and mortality in freshwater; (3) coho production in small east coast Vancouver Island streams, e.g. Nile and Chef creeks; and (4) early sealife of pink salmon from the Bella Coola River system in Burke Channel and other coastal waters of the British Columbia central mainland coast.

The concept of "key streams" (now referred to as "index streams" or "stream indexing") was revived recently with the Pearse Commission enquiry on Pacific Fisheries Policy (Pearse 1982). In one submission (Walters et al 1982) to the enquiry, it was noted that "there are considerable shortcomings in the way that this work (spawner enumeration) has been undertaken in the past". It was further suggested that: "One way in which the estimates could be improved is to standardize the survey process and observation sites so that officers can make more consistent estimates. To this end an 'index system' similar to that which is apparently quite successful in Washington State may be a worthwhile development (Ludwig and Walters 1981)".

Undoubtedly the foregoing comments, among others in the above submission, led to the recommendation in the Research and Information Chapter of the Final Pearse Commission Report (Pearse 1982, p.66-67):

"4. The Department should strengthen its programs of collecting and collating information on salmon and herring escapements and spawning by -

(iii) Developing new and consistent techniques for estimating spawning activity."

The Fisheries Research Branch of the Department of Fisheries and Oceans has responded to this recommendation by initiating a program of "stream indexing" to improve spawning escapement estimates. This report summarizes a proposal to carry out a long-term (15 years) pilot project in British Columbia to determine if the concept of index streams for improved salmon escapement estimates in this province is feasible. An "index stream" is defined here as one chosen to represent other streams in a given drainage basin or biogeoclimatic zone in terms of salmon escapement. Ultimately, the study should provide a better basis for development of stock-recruitment relationships for individual stocks.

2. BASIS FOR A STREAM INDEXING SYSTEM

The concept of stream indexing probably originates in hydrology, where it has been used to estimate streamflow. An index stream is selected for careful continuous streamflow measurements. The flows in other streams of the same drainage basin or geoclimatic zone are also monitored for a few years, and these flows are related to the flow in the index stream. Other variables influencing streamflow are monitored as well, such as precipitation, temperature, prevalence of ice and snow, and soil permeability. Over the long-term, it may be possible to estimate the flows of all streams in the watershed, based on the streamflow measurements in the index stream.

As far as I can judge from talking to hydrologists and engineers from the British Columbia Hydro and Power Authority and the Inland Waters Directorate of Environment Canada, stream indexing for flow estimation has not yet been attempted in British Columbia. There has been some reservation about undertaking such an approach in this province, because of the diversity of the terrain, the numerous geoclimatic zones through which a large

stream may flow, and the effects of varied soil conditions and vegetal cover (Fig. 1). Instead, there is a generally wide coverage with stream-gauging stations in the province to provide site-specific streamflow measurements (Fig. 2). Where the stream-indexing approach has been attempted, such as in Ontario, the terrain is somewhat more uniform than in British Columbia. It has been found even in these situations, however, that while the annual output of water from a stream can be estimated resonably well, the seasonal fluctuations in streamflow could not be extrapolated with any degree of accuracy from the index stream.

In applying a stream-indexing approach to spawning escapement, a number of other factors besides those affecting streamflow must be considered. The life-cycle of salmon, as depicted in Fig.3, is subjected to natural and man-made impacts at a number of points that affect ultimate escapement. In the first place, "effective spawning" must occur, which means that an optimum number of eggs must be deposited in the redd by a female and fertilized by a male. Because of various physical factors, e.g. high flows, low flows, siltation and freezing, the egg-to-fry survival can be seriously affected. Emerging fry are subjected to biotic and abiotic factors, such as predation and high stream flows, which can drastically reduce their numbers. The fry or smolts moving downstream can be further reduced by predation, starvation, disease and unfavourable habitat. There can be high mortality of the juveniles at sea for various reasons before recruitment to the fishery occurs. Finally, the fishery can harvest a considerable proportion of a stock, and the effect of harvesting is difficult to determine, especially in a mixed-stock fishery. How many of the fish are allowed to escape for purposes of spawning will be determined to some extent by the harvest-rate policy observed by management.

Notwithstanding the foregoing problems, stream indexing for salmon escapement estimates has been conducted, with some degree of success, in Washington State, Oregon and Alaska (Cousens et al. 1982). The mainstem of a river may be chosen for careful enumeration of spawners on which estimates of spawners in other streams of the area can be based. Alternatively, a tributary or a reach of the mainstem may be selected for careful enumeration, and the counts for the river system estimated from those data. Assorted techniques have been used in the U. S. Pacific Northwest States for spawner enumeration, the counting weir or fence being one of them. In Washington and Oregon, great reliance is placed on counting spawning salmon or redds from a helicopter. Alaska fisheries managers have moved to the side-scanning sonar to count salmon in some streams. These electronic counters have an advantage over visual counting in some of the turbid, glacial, silt-laden streams of Alaska, but must be properly calibrated against fence counts or some other appropriate visual technique.

Index streams have been used for estimating both spawning escapement and smolt migration of Atlantic salmon in the Gulf Region of the Department of Fisheries and Oceans (E.M.P.Chadwick, personal communication). There are some 147 Atlantic salmon rivers to be managed in the Gulf Region. The Fisheries Research Branch has selected 13 index streams on which spawning escapement and smolt counts are made with the aid of weirs or traps. The index stream counts are not used directly to predict counts in other streams in the area, but rather are used to provide an index of the strength of stocks in a particular fisheries statistical area. One index stream may represent 10 to 15 streams in an area. The Little Codroy River in southwestern Newfoundland has had precise smolt and spawning counts since 1983,

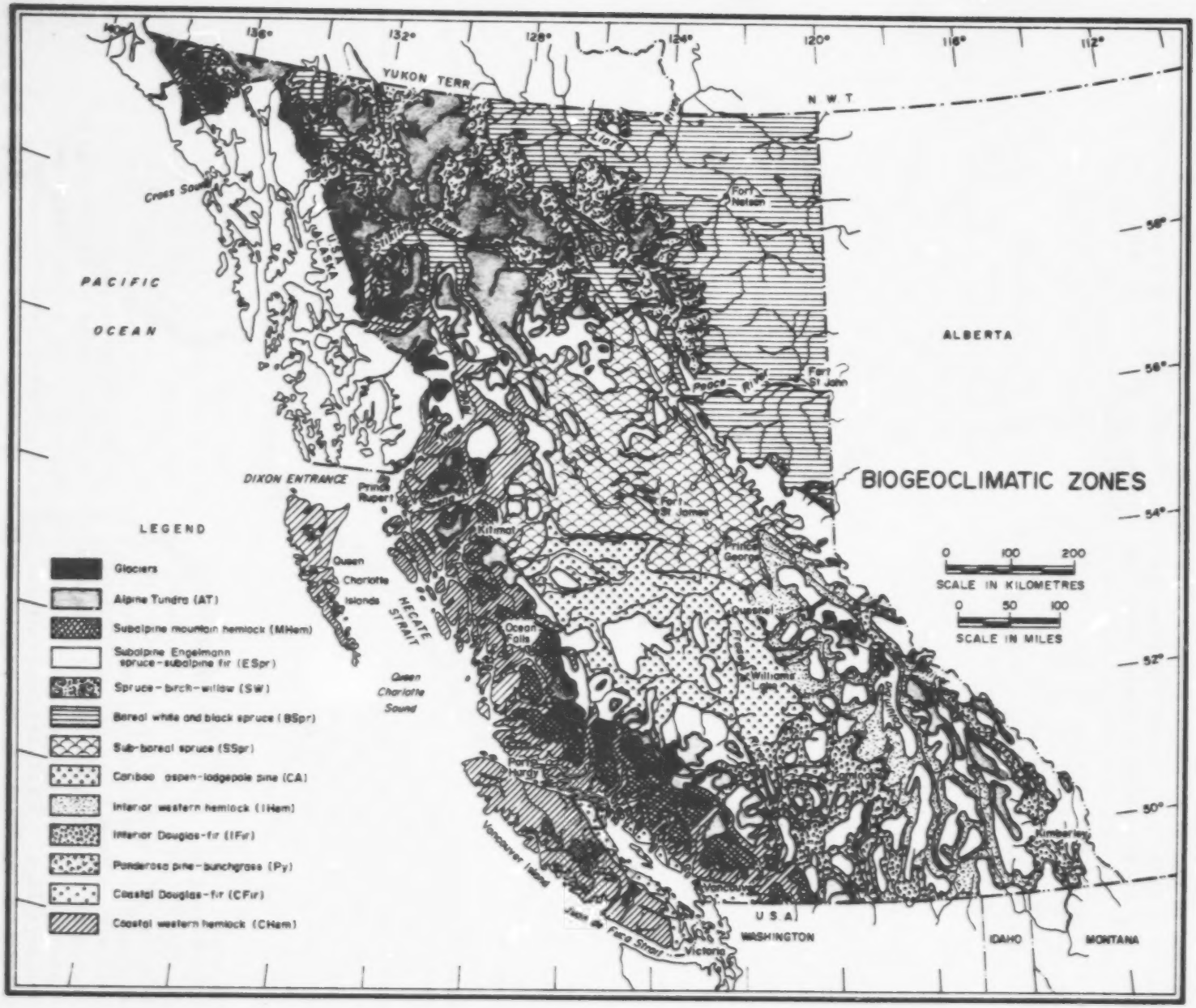

Fig. 1. Biogeoclimatic zones of British Columbia. (From Farley 1979).

Fig. 2. Hydrometric network in British Columbia.

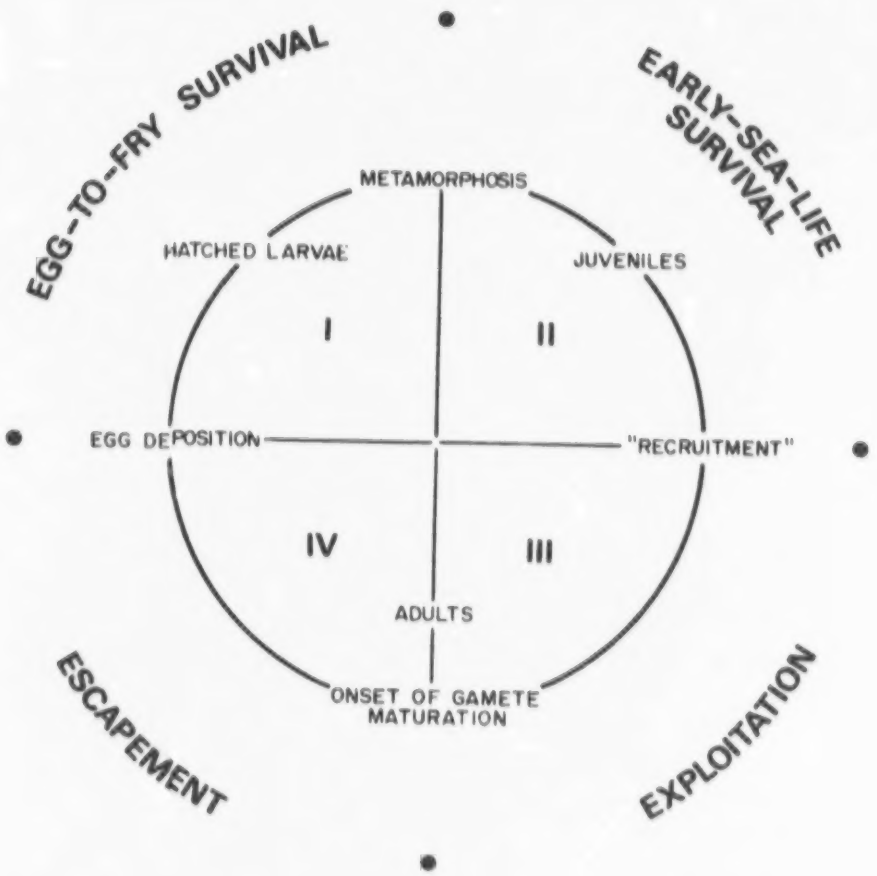

Fig. 3. A schematic diagram of the life-cycle of salmon, showing in the outer circle the stages when major natural and man-made impacts occur.

while precise Western Arm Brook spawner and smolt counts got underway in 1971. The Millbank traps on the Miramichi River have been in operation since 1954 and spawner counts there are now used even by the fishermen as an indicator of the health of Atlantic salmon stocks in this part of New Brunswick. In selection of an index stream in the Gulf Region, it has been important to consider the effects of both the commercial and sport fisheries on the stock. A stream with known heavy poaching is avoided as an index stream, because catch statistics are obviously incomplete.

3. SELECTION OF A PILOT STREAM-INDEXING STUDY AREA

There are a number of criteria that one must be able to fulfil in the choice of a suitable pilot area for conducting a stream-indexing study. Obviously a number of criteria cannot be fully fulfilled, because an ideal system may be extremely inaccessible or other factors may render it unsuitable.

3.1 Species for Stream-Indexing.

From a rather pragmatic point of view, a stream-indexing project should be oriented to the commercially-important species, sockeye and/or pinks. This is not to say that these species are the most likely to be amenable to a stream-indexing approach. In fact, the most positive success using stream indexing so far has been with coho in Oregon (Solazzi, These Proceedings). The Workshop on a Design of the B. C. Salmon Escapement Monitoring System (Hilborn 1983) recommended that some attempts should be made at developing index streams for coho. Others may suggest that because of the serious decline of chinook salmon in this province, an effort should be made on stream indexing for this species in an effort to restore the chinook stocks. After weighing all factors carefully, it has been decided that the order of priority of species for a stream-indexing pilot study should be: sockeye, pinks, chum, coho, chinook.

3.2 Area Selection

The area for a stream-indexing study should be reasonably accessible by road. If it is a long way from Vancouver and Nanaimo, i.e., in the northern or central area of the province, accessibility by air would be desirable. There should be at least 5 or 6 streams in rather close proximity (Fig.4), and these should preferably all be in the same drainage basin, as shown in Fig. 5. Ideally, at least one of the streams should be gauged for streamflow in the hydrometric network of British Columbia (Fig.2). If it is in fact possible to do so, a pilot area should be chosen in such a way that it is reasonably representative of a large part of the province biogeoclimatically (see Fig. 1).

3.3. Existing Spawning and Smolt Count Data

There is much merit in selecting a pilot study area where there is at least one stream in which precise salmon spawning counts and smolt counts have been made at a fence over a period of a decade or more. This would provide a good basis on which to commence a stream-indexing project. An existing counting fence on one of the streams would be a bonus.

3.4 Size of Streams and Salmon Runs and Artificial Perturbations.

Streams chosen for a pilot stream-indexing study should not be too

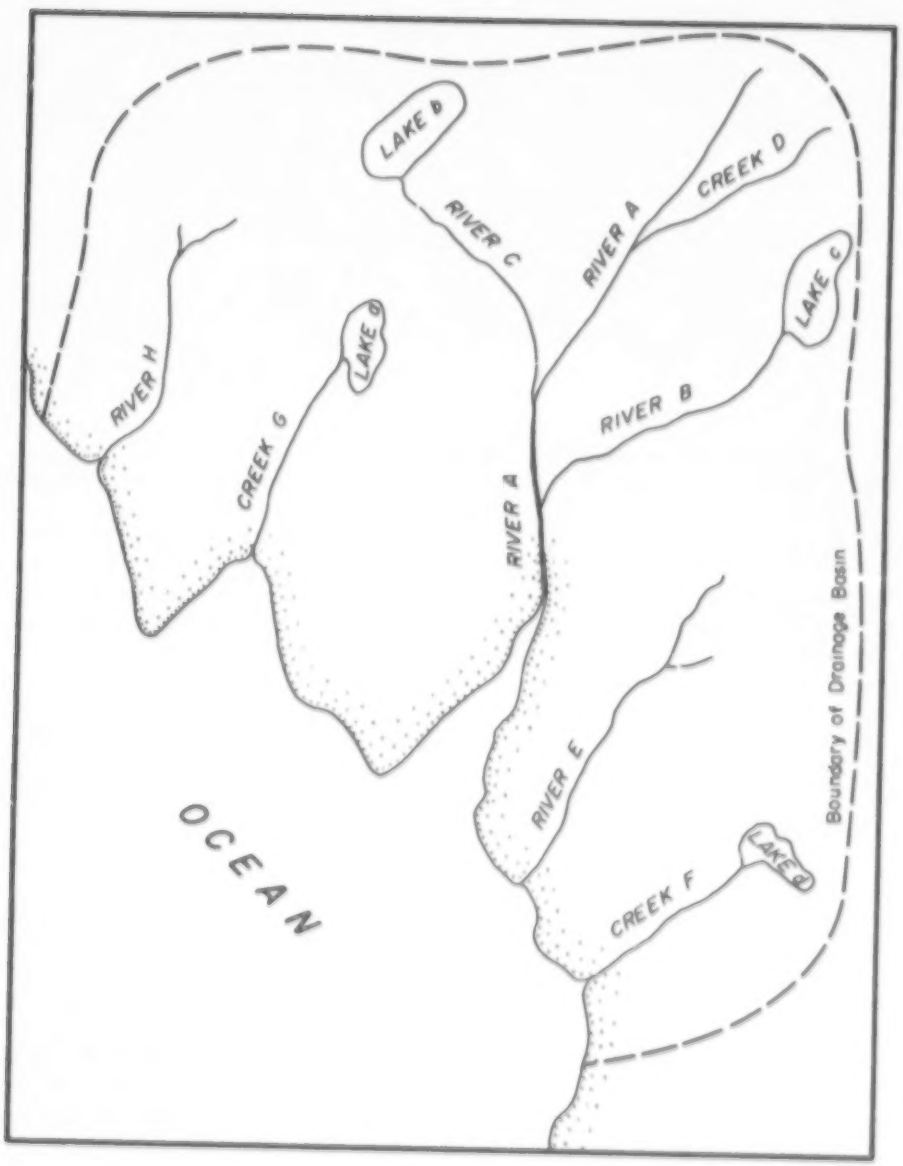

Fig. 4. A hypothetical pilot area for a stream indexing study, where an "index stream" might be selected to represent other streams in the area.

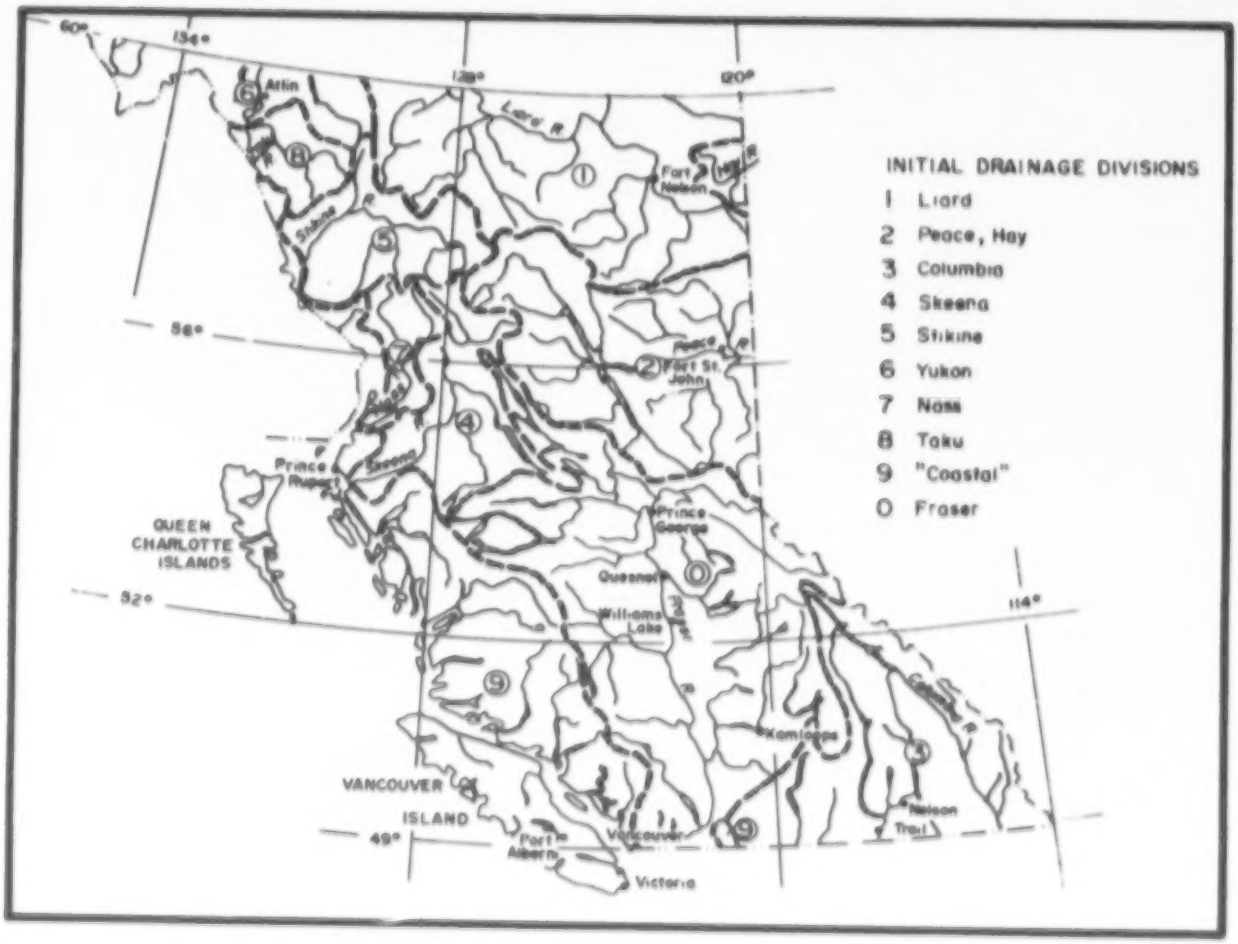

Fig. 5. Initial drainage divisions of British Columbia.

large. An average flow of 28 $m^3 sec^{-1}$ (1000 c.f.s.), with a low flow-to-high flow ratio not exceeding 1:50, may be ideal. Smaller streams of half that flow might be useful also, but streams much larger become rather difficult to equip with a fence, especially if they undergo large seasonal fluctuations in streamflow.

Runs of the salmon species of interest should not be too small, i.e., not less than 1000 spawners. Small runs tend to be difficult to assess statistically. Runs should also not be too large, because a great deal of effort may be required for enumeration. The most useful range of adults is 1,000 to 10,000 spawners, although up to 50,000 spawners might be coped with reasonably well.

Streams that have not been perturbed by such man-made effects as logging or salmonid enhancement with hatcheries and spawning channels, should be sought. Natural runs in undisturbed streams would be preferable.

3.5 Salmon Stocks with Reliable Catch Data

Ideally, streams should be chosen that have stocks for which there are good catch data, and which are not subjected to a mixed-stock fishery. If this is impossible to attain, there should be some assurance that the stocks from the selected streams can be identified in the fishery.

3.6 Streams with Synchronous Fluctuations in Escapements

Existing spawning escapement data can be used to find an area in the province where streams show some coherence in their escapement fluctuations from year to year. Such synchrony in escapements may be difficult to find. It may be necessary to consider catch data, as well as escapement data, to make any sense of year-to-year fluctuations of stocks in streams of a given drainage basin. Only the three major stocks in Barkley Sound (Great Central, Sproat and Henderson lake stocks) have been found to exhibit synchronous year-to-year fluctuations. An example for Statistical Area 3 (see Fig.6) shows rather erratic year-to-year fluctuations in sockeye escapement to different streams for the period 1947-1982, although there has been a trend of increasing escapement in the major stocks during that period (Fig.7). The data plotted in Fig.7 were taken from Hancock et al (1983), who used escapement information provided by fishery officers on B. C. 16 forms, from which a mean was calculated if a range for an escapement estimate was given (e.g., mean of 7,500 for a reported range of 5,000 to 10,000 escapement).

4. OPERATIONAL PLAN FOR THE PILOT STUDY.

While the core of any stream-indexing pilot study must be enumeration of spawning adults and downstream juveniles, there must be other studies to provide needed information on factors affecting production of salmon in streams. The stream ecology is very important. This section outlines an holistic approach needed for a fuller understanding on what makes a salmon stream productive, and why indexing works or does not work.

4.1 Time Frame.

Any stream indexing study must be considered a long-term (at least 15 years) project. For a species like sockeye, with an average 4-year life cycle, this 15-year time frame would yield nearly four generations. It should begin to provide a statistical base on which an assessment of the validity of stream indexing could be made. For pinks, with a two-year life cycle, at least seven generations could be realized, which provide an even better statistical basis for evaluation.

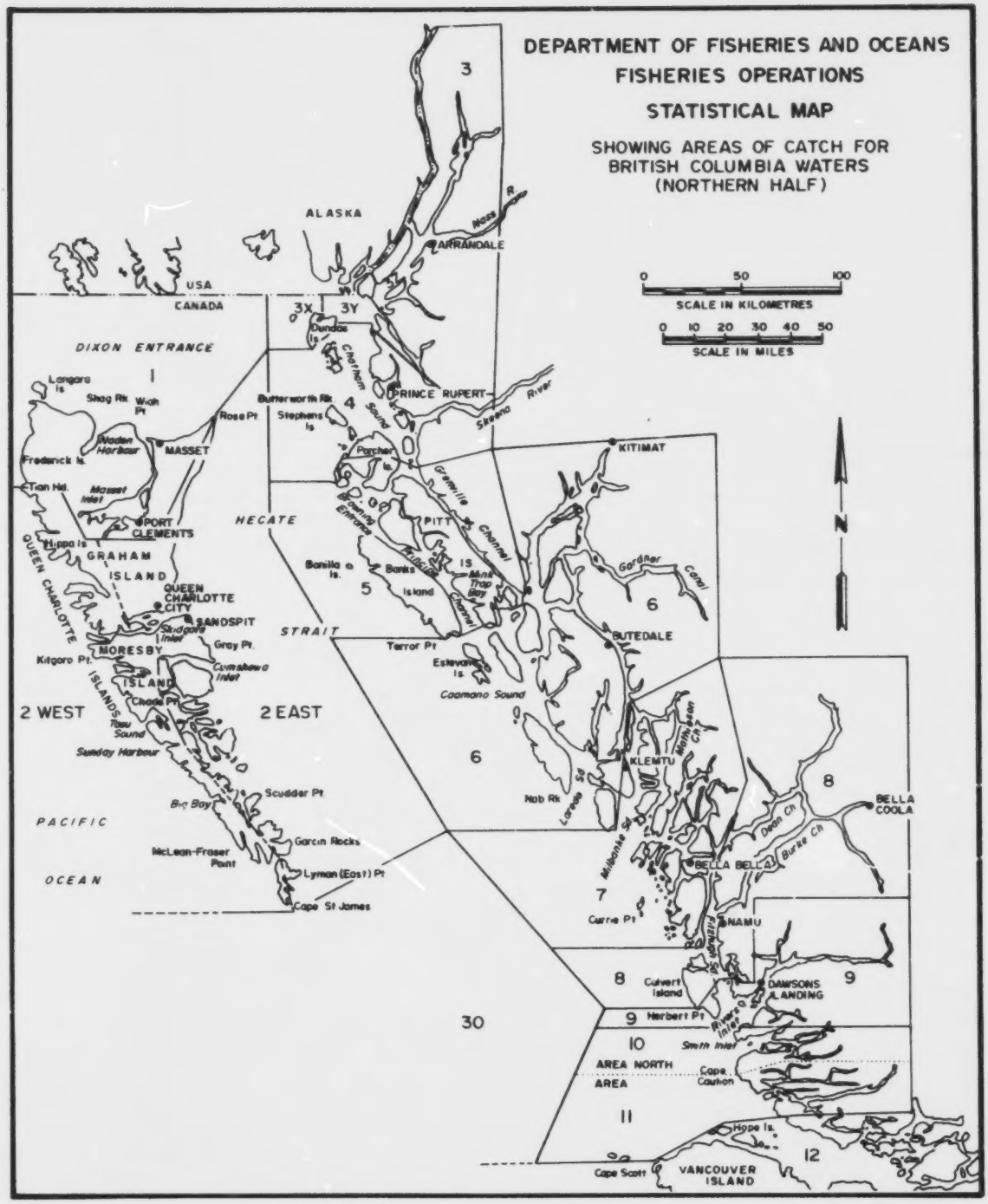

Fig. 6. Statistical fisheries areas of Northern British Columbia.

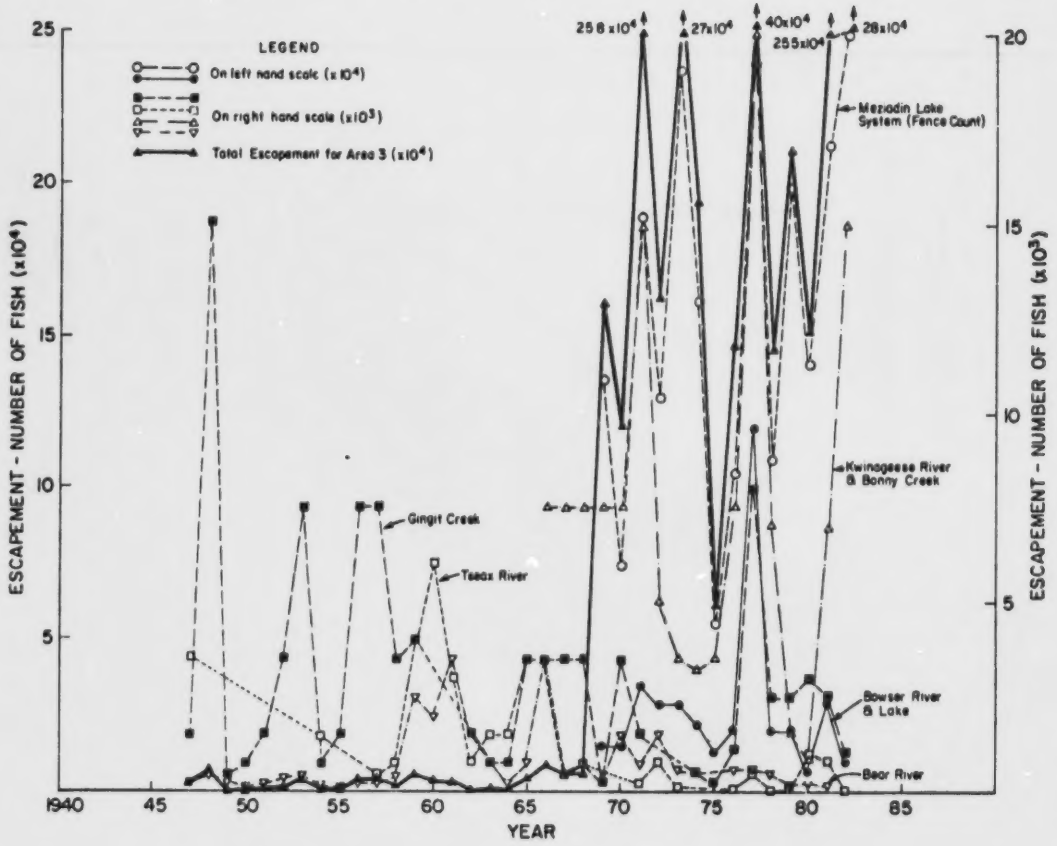

Fig. 7. Year-to-year fluctuations in sockeye spawning escapement in Statistical Fisheries Area 3. (see Fig. 6 for location). Except for the Meziadin Lake system, where escapements were enumerated by fence counts, all escapement estimates were made by fishery officers' stream surveys, usually on foot.

4.2 Stream Selection

Once the pilot area is identified, about 6 streams should be selected for continuous monitoring. Ideally, these should be individual streams of the size described in section 3.4, all of which drain either directly into the sea or into a larger river. They should be chosen with an eye for ease of escapement enumeration, either with a fence or an appropriate electronic counter. Some consideration should be given to stock identification and the availability of good catch data for the stock(s) (see section 3.5).

4.3 Escapement Enumeration

Part of the core program for a stream indexing pilot study must be escapement enumeration. Streams selected for the study should be examined carefully to determine how precise and accurate escapement counts will be made. At least one of the five or six streams selected should be considered for installation of a permanent counting fence, if one does not already exist there. Installation of temporary fences on other streams in the area would be desirable. Enumeration of spawners on other streams may be possible with a reasonable degree of precision and accuracy, using a side-scan sonar of the Bendix type or an electronic counter of the Pulsar design. Doppler-type counters are now available, and initial tests suggest that they can be useful for escapement enumeration. Counting towers may be another alternative, although they tend to be labour-intensive. Aerial surveys by helicopter are another option, and selection of streams should in part be based on unobstructed aerial views of spawning grounds. In some cases, it may be necessary to carry out a mark-and-recapture program for enumeration, recognizing that this can considerably over-estimate the escapement (Brett 1952).

As part of the spawning enumeration program, scale and/or otolith samples should be taken for age determination.

4.4 Fry and Smolt Counts

Enumeration of downstream migrants may very well be as important, if not more important, as enumeration of spawners in a stream-indexing study. There should be a plan to eventually determine the annual output of smolts from each stream. This may be done in the traditional way by counting in traps at a weir or a suitable counting fence. A weir partly across a stream with traps may be used, but an estimate of the absolute numbers of juveniles passing through would have to be determined by a reliable estimate of the proportion of the run of juveniles captured in the traps.

Because egg-to-fry survival is so important in establishing the number of smolts migrating to sea, it would be desirable to undertake egg-to-fry survival studies in the selected streams over a reasonably long period (perhaps 5 years). This would provide an estimate of the effectiveness of a given number of spawners in contributing to a particular year-class of salmon and a measure of the variability of egg-to-fry survival from year to year and the differences among streams in the same area.

4.5 Observations of Abiotic Factors

Concurrently with the upstream and downstream counting operations, some of the physical and chemical characteristics of the streams should be monitored.

4.5.1 Stream flow. - A system of gauging the streams for flow should be initiated, preferably with the assistance of the Water Survey of

Canada in the Inland Waters Directorate of Environment Canada. By a fortunate choice of streams for the pilot study, it is possible that one or two of the streams are already gauged for streamflow.

4.5.2 Sediment load. - Deposition of sediment on the spawning grounds may have an effect on salmon eggs and fry. A program of daily, or at least weekly, turbidity and suspended-sediment measurements may prove to be of value in relating egg-to-fry survival to environmental conditions. Again, the cooperation of the Water Survey of Canada, who also carry-out sediment-load surveys in streams, should be sought.

4.5.3 Temperature. - An environmental characteristic that can have both lethal and sub-lethal effects at its extreme ranges, temperature is one of the easiest variables to measure. It should be measured daily, or even continuously on a thermograph, to provide a record of any unusual temperatures in the streams that may have had an impact on adults or juveniles.

4.5.4 Dissolved oxygen. - The concentration of dissolved oxygen is particularly important on the spawning grounds. An occasional check of dissolved oxygen concentration, especially during warm, low-flow periods, may reveal problems for egg and fry survival.

4.5.5 Hydrogen-ion concentration (pH). - Many of the coastal streams in British Columbia are in the acid-sensitive geological regime of the province. There has been some concern about increasing acidity (decreasing pH) as a result of acid precipitation, in certain salmon-bearing waters. Again, pH is one of the easier measurements to conduct, and it would be desirable to maintain a daily or weekly record of pH in all streams of the pilot area to identify any undesirable trends in acidity over the period of the study.

4.5.6 Nutrients. - It is not anticipated that there would be much variation in nutrients (phosphates, nitrates and silicates) in different streams of the same biogeoclimatic zone. Nevertheless, occasional nutrient determinations may prove useful in identifying anomalous conditions in water fertility that may arise from natural or man-made causes.

4.6 Other Biological Observations

4.6.1 Primary Productivity. - Ultimately, the food supply for the juvenile stages of salmonids has to stem from the primary production in the system, aside from leaf litter and other organic material that may be introduced from extraneous sources. The primary production may be in the form of phytoplankton in the stream or periphyton on the substrate. Knowledge of the primary production in each stream of the pilot area is desirable, as possibly affecting salmon production in the stream, but high priority cannot be placed on it in an integrated program of studies. More practical information may come from the next trophic level, i.e., zooplankton and benthic invertebrates. Studies of primary productivity in the streams would be appropriate for more academic pursuits by graduate students, post-doctoral fellows, visiting scientists or university professors.

4.6.2 Secondary Productivity. - The food of the various post-alevin stages of juvenile salmon appears to be the secondary producers.

Various juvenile stages of aquatic insects, zooplankton and benthic invertebrates have been reported as the favoured food of juvenile salmon during the stream stage of their life cycle. It is obvious that studies will be required eventually on the feeding habits of juvenile salmon in the streams of the pilot area and on how salmon production is affected by availability of food and by factors that affect food availability. This type of research might be particularly suitable for a cooperative study involving specialists from universities or other scientific establishments.

4.6.2 Predation. - Juvenile salmon are prey for many other species, including other salmonids, present in their habitat. Because predation can have a significant impact on the number of smolts eventually reaching the sea, an estimate of this effect must be obtained in a stream-indexing pilot study. A project to study predation in a stream cannot be considered part of the routine observations but must be regarded as a more specialized study. Again, it is amenable for cooperative research by a specialist or by a graduate student.

5. A SYSTEM OF INDEX STREAMS IN BRITISH COLUMBIA

If the Stream-Indexing Pilot Study demonstrates that an index stream can validly be selected to represent other streams in a given drainage basin or biogeoclimatic zone, then the next logical step would be to select index streams in other parts of the province. A first step in such an expansion of an index-stream network might be selection of streams in other biogeoclimatic zones in the province, not represented by the pilot area, and test the index-stream concept there. Once it is confirmed that the index-stream concept applies generally in the province, then the network can be appropriately expanded to other areas. Fisheries officers and management biologists could become involved in procuring the more precise and accurate spawning and smolt data for index streams in various Fisheries and Oceans Districts and Sub-Districts.

A system of index streams should not be construed as one that would eliminate the need for continuing spawn surveys by fishery officers in the various spawning streams of the province. Such information would continue to be required. The index stream system, however, would be one way of upgrading the precision and accuracy of fishery officers' spawning estimates, by comparing stream counts with more precise and accurate fence or electronic counter counts.

On the other hand, it might be concluded after the study is completed that no such thing as an "index stream", at least within the narrow confines of the definition given in the Introduction, exists in this province. Index streams might serve in that case only as a general indicator of the health of the stocks in the areas of the index streams. This in itself may be a sufficient basis for the establishment of a network of index streams.

In any case, the pilot study should provide a basis for upgrading the precision and accuracy of escapement estimates acquired by fishery officers. Standardization of escapement enumeration techniques might be better achieved to provide consistency. Moreover, it is hoped that the pilot study will identify some of the biotic and abiotic characteristics of streams that are important in determining their productive capacities and variability in terms of salmon. Such knowledge should provide a better basis for establishing stock-recruitment relationships for streams and prediction

of sizes of runs for better management.

6. CONCLUSIONS

The proposed pilot study is designed to test the concept of stream indexing, where an index stream is defined as a stream chosen to represent other streams in a given drainage basin or geoclimatic zone in terms of salmon escapements. The basic objective of a stream indexing project is to improve salmon escapement estimates for better management of the salmonid resource in British Columbia. The duration of the project should be at least 15 years to provide a sufficiently long data series for valid statistical evaluation.

It is proposed to select a pilot area with about six streams having an average flow of about $30 m^3 sec^{-1}$ in which the ratio of peak flow to low flow is no greater than 50:1. Emphasis will be placed on sockeye and pinks. While escapement enumeration will be part of the core program, it will be essential also to enumerate fry and smolt output from each stream (smolt output may be even more important than spawner numbers). Abiotic factors should be monitored for each stream during the course of the study, including streamflow. turbidity and suspended sediments, temperature, and pH. Occasional measurements of dissolved oxygen and nutrients (phosphate, nitrate and silicate) should be made as well. Other biological observations should be conducted, such as the feeding of salmon juveniles and predation on them. Certain studies, such as the primary productivity of the streams, could be conducted in cooperative research by visiting scientists. Some of the ancillary studies, over and above the basic spawner and juvenile counting activities, should provide a fuller picture of the stream ecology that contributes to the salmon productivity of a given stream. They should assist in determining the stock-recruitment relationships for individual stocks and in predicting the sizes of runs.

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STREAM INDEXING FROM THE PERSPECTIVE OF THE CARNATION CREEK EXPERIENCE

by

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INTRODUCTION

The procedure of indexing streams for regional salmon escapement forecasting may have as its ultimate objectives: (a) the forecasting of numbers of smolts and future returns from those smolts on a regional scale; and (b) the enabling of real-time management of a terminal fishery. In achieving the first objective, one assumes that there is a useful relationship between escapement and subsequent recruitment and then between recruitment and subsequent escapement. The existence of such a stock-recruitment relationship would permit the forecasting of future returns from measured escapements. Assuming that the stock-recruitment relationship is generally valid within a region, escapement forecasts for that region could then be made from measured escapement on a single indexed stream. In addressing the second objective, one assumes that the timing of entry for returning adults into rivers and creeks is consistent throughout a geographical region. By counting, in real-time, the escapement on a single river, managers could presumably assess the magnitude of escapement to all surrounding systems and make the appropriate management decisions regarding openings and quotas for the terminal fishery.

Our comments on these two objectives are largely based on reported data for the coho salmon and cutthroat and rainbow trout of Carnation Creek and some neighbouring streams in the Barkley Sound area (Andersen 1983, 1984). We will suggest that:

1. Useful and predictive smolt-adult relationships can be derived for Carnation Creek coho. The predictor variables that are employed suggest that the coincidental catch in the terminal net fishery for chum and sockeye in Barkley Sound is a major determinant of escapement to Carnation Creek. Early marine survival is of lesser importance.

2. For Carnation Creek coho, smolt production cannot be predicted from escapements, at least over the range of escapements observed to date (43-176 females).

3. The average production of coho smolts from a diverse set of streams on the mainland and the east coast of Vancouver Island can be predicted through a simple relationship to stream length. This relationship is a poor point predictor and would require considerable refinement before it could be used to make predictions other than long-term averages. Relationships developed for Carnation Creek itself employ a set of climatic variables. These relationships would probably be useful in indexing production from other streams in the region that experience the same climate. Their utility would be limited by the sensitivity of the relationships to changes in the patterns of land-use.

4. Time series of late summer population estimates and sizes of juvenile salmonids in streams of the Barkley Sound region are similar, indicating that one or more of the many factors controlling population levels is operating on a regional scale. For salmon, the patterns of covariation suggest that the factor is not related to escapement, but rather to some instream mortality factor.

5. The patterns and timing of coho escapement to small intermittent streams, such as Carnation Creek, are such that the second objective of stream indexing (real-time management) is not possible.

Smolt-adult Relationships

The first step in quantifying the stock-recruitment relationship is establishing the relationship between the numbers of returning adults and the numbers of smolts.

Twelve years of complete data for Carnation Creek coho returns are now available. Virtually all of the outmigrating smolts and the returning jacks and adults are enumerated and sized at the fish fence on the creek. Errors in these measurements are thought to be small and are certainly less than 20%. However, there are no estimates of the numbers of fish taken in the commercial and sport fisheries. Consequently, the relationship between the number of adults returning to Carnation Creek and the number of smolts would be useful only if fishing mortality had varied randomly with time. The observed returns to the creek would then be the actual returns minus the mean fishing mortality with its associated error term.

There is circumstantial evidence that fishing mortality has systematically increased with time since the beginning of the study. Since the number of smolts and their size has also increased with time, the apparent smolt-adult relationship is probably confounded by three time trends.

The effort, exerted by fishermen in the Barkley Sound net fisheries, averaged for chum, coho and sockeye, was determined from sales slip records. Effort has increased exponentially with time from 1972 through 1981, the last year for which there are data (Fig. 1). Proportional returns of both 1.1 and 2.1 males and females to the creek are negatively correlated with both time and with average fishing effort (Fig. 2). Proportional jack returns, however, are not correlated with fishing effort.

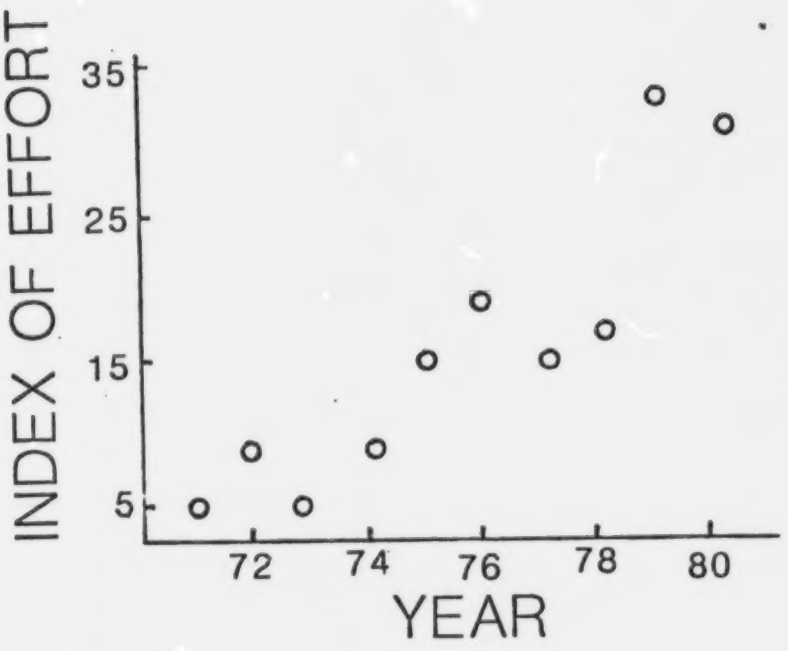

Fig. 1. An index of the average effort exerted in the terminal net fisheries for sockeye, chum and coho in Barkley Sound versus time. The data were obtained from sales slip records.

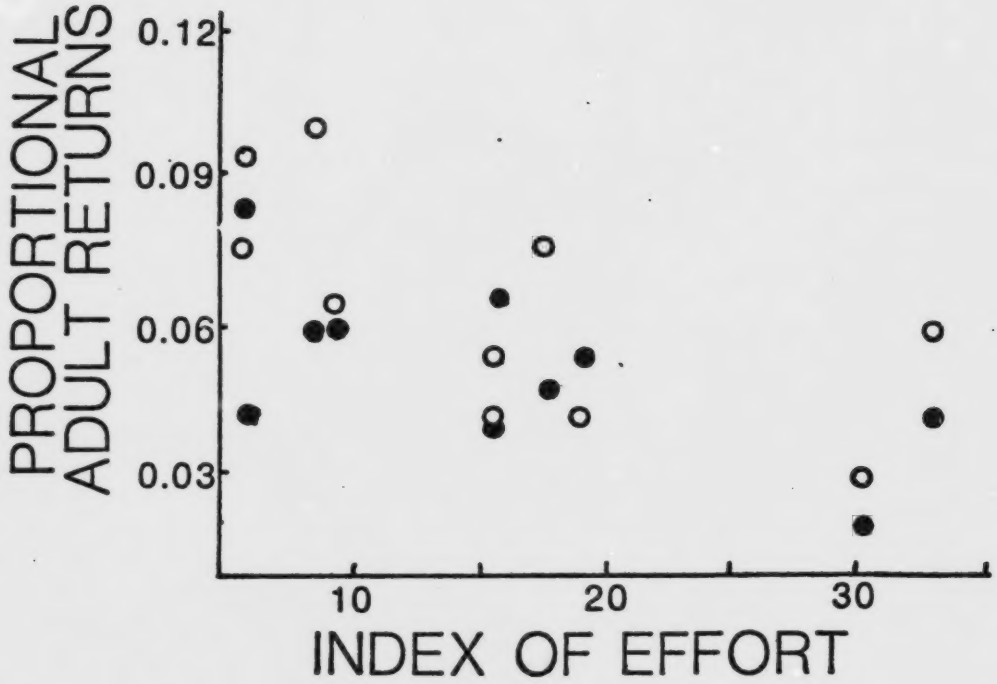

Fig. 2. Proportional adult coho returns to Carnation Creek versus the index of average effort exerted in the terminal net fisheries in Barkley Sound. Proportional returns are the numbers of large males and females divided by the total smolt output. The two age classes of adults (1.1 and 2.1) have been treated separately.

Since jacks are probably not susceptible to the terminal net fishery, we infer that the adult fish were being subjected to increasing mortality from the terminal fishery.

This argument could be confounded by the trend to increased smolt size with time. If jacking rate is a function of size, then a decreased return of jacks due to a factor correlated with the fishery or due to the fishery itself, would have been masked by a size-related increase in the jacking rate. Proportional returns of jacks do increase signficantly with size if both the 1. and 2. fish are considered together ($r=0.586$; $p<0.01$), but correlations are not significant when the two age groups are separated (1. jacks $r=0.159$; $p>0.1$; 2. jacks $r=0.417$; $p>0.1$). This pattern of correlations suggests that there is a real difference in the jacking rates of 1. and 2. smolts, but that within each age group, the jacking rate is not strongly dependent on size.

The form of the smolt-adult relationship, without regard to the fishery (Fig. 3), suggests density-dependent marine survival and is statistically consistent with density dependence (sensu Peterman 1982). This density-dependence is, however, largely an artifact of the coincidence of parallel increases in both smolt numbers and (presumed) fishing pressures. Since smolt numbers have been increasing with time and proportional returns have been decreasing with time owing to the fishery, the slope of the $\log_e$ (adult) versus $\log_e$ (smolt) line is significantly less than one (Holtby and Hartman 1982).

Although the "real" smolt-adult relationship cannot be known without independent information about the number of fish taken in the fisheries, a relationship can be reconstructed. Proportional adult returns of 1. and 2. fish to Carnation Creek can be predicted from the observed effort in the terminal net fishery and from presumed correlates of early ocean survival (Table 1). Holding the predictive variables at their values in any particular year (1971 is shown; Table 2), estimated total returns can be calculated. The exponent of the reconstructed smolt-adult relationship (Fig. 3) is not significantly different from 1.0 Therefore, adult returns are proportional to smolt output, i.e., a doubling of smolt numbers will, on average, produce a doubling of adults.

If it is further assumed that the exploitation rate of the troll fishery in the early 1970's was 60% (M. C. Healey, pers. comm.) and that the exploitation rate has not changed systematically since, then the catch of the fishery (the offshore troll and the Barkley Sound net fishery) and the current exploitation rate can be estimated (Table 2). This calculation suggests that exploitation rates have now reached approximately 81% on the Carnation Creek coho population. Increased effort in the Barkley Sound net fishery has resulted in an increase in the exploitation rate on the Carnation Creek coho of approximately 26%.

After correcting for systematic variation in the fishery and, to a lesser extent, for presumed variation in non-fisheries ocean mortality, adult returns are proportional to smolt numbers. Actual average survivals cannot be determined without independent measures of exploitation rates, but a range of plausible survivals could be easily calculated based on assumptions about historical exploitation rates.

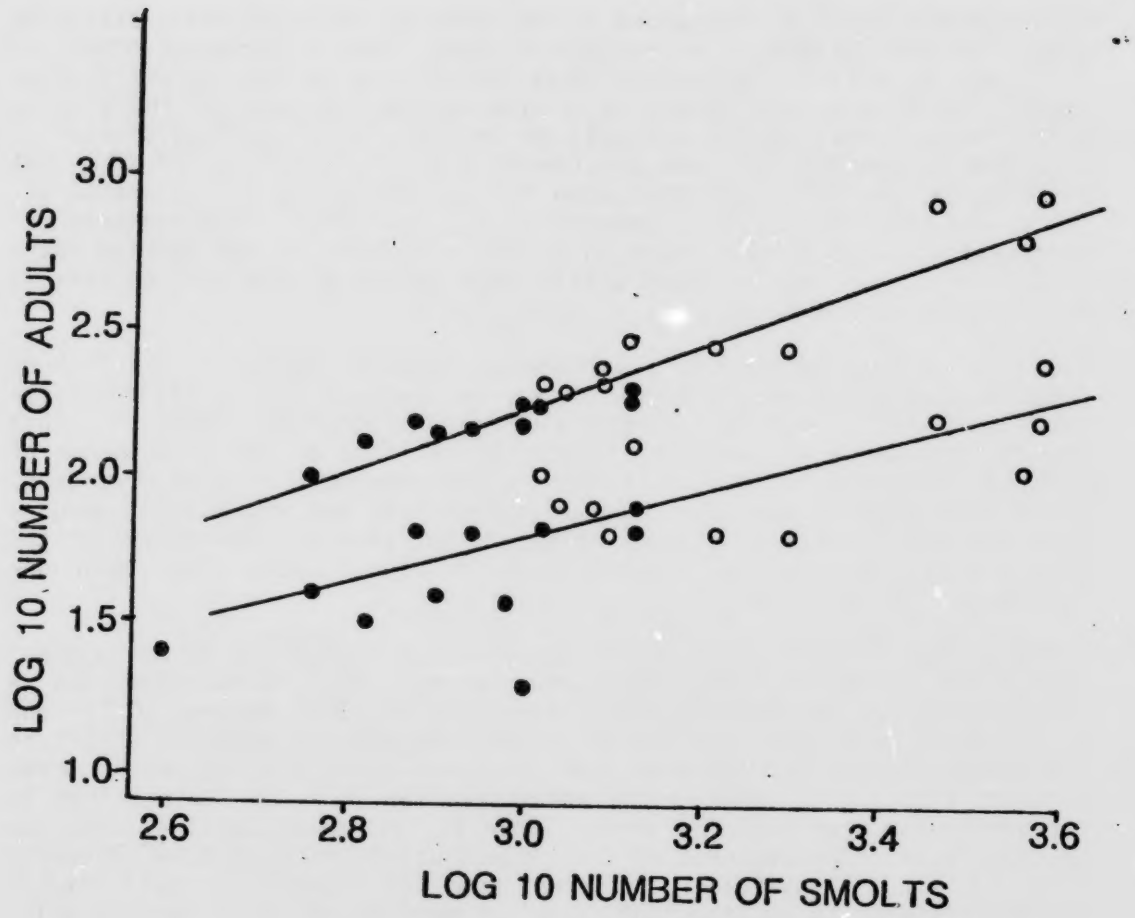

Fig. 3. The numbers of adult coho returning to Carnation Creek versus the number of smolts. The lower line is the observed relationship, uncorrected for any fishery. The upper line is the reconstructed adult-smolt relationship corrected for both the terminal net fishery in Barkely Sound and the offshore troll fishery. Solid circles are 2.1 fish, open circles are 1.1 fish. The slope of the lower line is 0.8339 and is significantly less than 1.0 at the 5% level. The slope of the upper line is 0.9883, which is not significantly different from 1. The R^2 values for the two relationships are 0.663 for the lower line and 0.913 for the upper relationship.

TABLE 1. Predictive regressions for the proportion of smolts that return as 1.1 and 2.1 adults (excludes jacks). Average effort is the average of the effort exerted in the terminal net fisheries for coho, chum and sockeye in Barkley Sound as recorded by sales slips. p(jack 1.0) is the proportion of smolts that returned as 1.0 jacks in the year prior to the adult return; i.e., they are jacks that returned from the same smolt run. CPUEWVI is the catch per unit effort in the coho troll fishery for statistical areas 21, 23, 24, 25, 26 and 27 as reported on sales slips. The CPUE was reported for the same year as the return of adults to Carnation Creek. R^2 is the coefficient of multiple determination corrected for degrees of freedom.

p(adult 1.1) = 0.0563 - 0.001402 x average effort
+ 1.273 x p(jack 1.0)

R^2 = 0.804

p(adult 2.1) = 0.0330 - 0.00175 x average effort
+ 0.03516 x CPUEWVI

R^2 = 0.625

TABLE 2. The estimation of exploitation rates on Carnation Creek coho. Predicted proportional returns (P_{ret}) were obtained from the regressions in Table 1, while holding average effort in the Barkley Sound net fishery at its 1971 value of 5.34. Predicted returns of adults, after the net fishery (A_e), were calculated from P_{ret} and the observed numbers of smolts. The total exploitation rate (ER_{tot}) was calculated assuming that the troll fishery off the west coast of Vancouver Island has had a constant exploitation rate of 60%. $ER_{net}=ER_{tot}-0.6$, is the relative exploitation rate due to the net fishery in Barkley Sound.

	Year	P_{ret}	A_e	A_{obs}	ER_{tot}	ER_{net}
1.1 ADULTS	71	0.0838	89.0	99	0.555	0
	72	0.0899	120.9	128	0.577	0
	73	0.0701	78.1	82	0.580	0
	74	0.0702	85.2	73	0.657	0.057
	75	0.0750	93.6	64	0.726	0.126
	76	0.0550	109.8	68	0.752	0.152
	77	0.0696	113.1	64	0.774	0.174
	78	0.0852	329.7	173	0.790	0.170
	79	0.0878	251.3	162	0.742	0.142
	80	0.0687	245.6	99	0.839	0.239
2.1 ADULTS	71	0.0549	77.7	63	0.676	0.076
	72	0.0701	40.2	36	0.642	0.042
	73	0.0792	61.5	66	0.571	0
	74	0.0528	76.3	85	0.554	0
	75	0.0841	73.5	59	0.679	0.079
	76	0.0708	75.6	59	0.668	0.068
	77	0.0665	62.2	38	0.756	0.156
	78	0.0792	61.6	39	0.747	0.147
	79	0.0792	52.9	29	0.781	0.181
	80	0.0760	75.3	20	0.894	0.294

Our ability to predict adult returns, at least in a relative sense, is encouraging, but hardly novel. It remains to be seen whether the predictive relationships that we have developed could be applied to other nearby streams. Given that smolt and adult behaviour of neighbouring coho populations are similar, smolt-adult relationships should be similar within a region, especially in a relative sense.

2. Prediction of Smolt Production

Having demonstrated our ability to predict adult returns from smolt production, the relationship between escapement and smolt production must now be elucidated in order that the stock-recruitment relationship be quantified.

For Carnation Creek coho, there is no simple relationship between number of smolts and numbers of female spawners, even when logging activity is recognized (Fig. 4). It may be argued that this is not unexpected for coho where, given "adequate" escapement, smolt production is thought to be limited by the available rearing space (Chapman 1966; Burns 1971). This possibility considerably complicates the problem of defining the stock-recruitment relationship, because both the "carrying capacity" and the inflection point of the stock-recruitment curve must be predictable.

The task of predicting the carrying capacity of a stream has received by far the most attention. Smolt production may be estimated through a relationship to available habitat space. Over a broad geographic area (California to Alaska), smolt production is proportional to stream length (Table 3). The strength of this relationship is surprising considering the latitude covered. Smolt production must surely be determined to some extent by stream productivity, and it is unlikely that all of the streams used had similar productivities. This factor probably accounts for the overestimation of smolt production from Carnation Creek prior to logging (Table 4). There was no similarly oligotrophic stream in the data set. After logging, smolt production from Carnation Creek is predicted well. Although the confidence bands around estimates of average smolt production are not large, point estimates of production are very uncertain (Table 4). General relationships such as this one could be useful in predicting average smolt production, but would be of little use in indicating trends over short periods of time.

Predictive relationships have been developed for Carnation Creek coho (Table 5; Holtby and Hartman 1982). Although these relationships are adequate predictors of smolt production within that system, it is likely that they could not be applied quantitatively to other creeks in the area. However, the predictor variables in these relationships are all climatic variables, and it is possible that smolt production in streams subject to the same climatic variability would be indexed by production from Carnation Creek. The advantage of relationships developed for specific streams or groups of streams is that they can be used to accurately predict smolt production in any one year. Such predictions are necessary to reliably detect short-term changes in smolt production, and to ascribe observed changes to fluctuating escapements or changes in stream conditions.

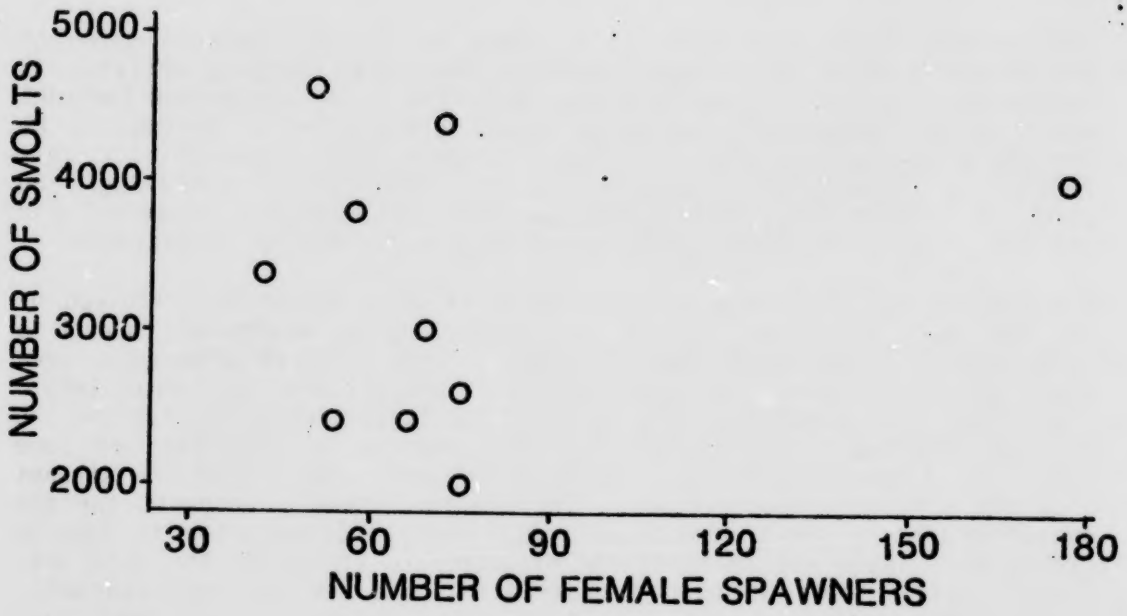

Fig. 4. The relationship between the number of female spawners and the smolts they produce. Smolt numbers are totals of 1+ and 2+ smolts in successive years.

TABLE 3. Smolt production in numbers and total weight related to stream length. The data are from Marshall and Britton (1980). For smolt numbers, there were 37 systems with 121 total observations. For total smolt weight, there were data from 20 systems with 50 observations. L is the accessible stream length in kilometres. The explained variance, corrected for degrees of freedom is given by r^2.

$$\text{smolt number} = 1045 \times L^{1.1801} \qquad r^2 = 0.779$$

$$\text{total smolt weight (kg)} = 7.094 \times L^{1.328} \qquad r^2 = 0.757$$

TABLE 4. Predicted and observed smolt production from Carnation Creek. L for Carnation Creek is 3.07 km. Prelogging years were 1971-1976; post-logging years were 1977-1982. The 95% confidence intervals for two predictions are given, one for the mean smolt production and the other for a single or point estimate of production.

	95% Confidence Intervals			
	mean production	point estimate of production	observed production	predicted / observed
smolt numbers				
pre-logging	3635-4238	2061-7477	2384	1.65
post-logging	3635-4238	2061-7477	3950	0.99
smolt weight				
pre-logging	23.6-42.0	7.1-139	15.8	1.99
post-logging	23.6-42.0	7.1-139	27.8	1.13

TABLE 5. Predictive regressions for smolt yield from Carnation Creek. R^2 is the coefficient of multiple determination corrected for degrees of freedom.

Dependent Variable	Independent Variable	Parameter Estimate	Cumulative R^2
Smolt number per metre	(intercept)	0.5435	----
	summer thermal summation (°C days)	0.00201	0.544
	min. winter temperature (0°C)	0.1606	0.745
	$\log_{10}$ max. mean - daily winter flow (cfs)	-1.0231	0.857
Smolt weight ($kg.km^{-1}$)	(intercept)	0.01148	----
	summer thermal summation (°C)	0.00001798	0.500
	$\log_{10}$ max. mean - daily winter flow (cfs)	-0.01029	0.795
	total flow Nov. 1 to Mar 31 ($cf \times 10^8$)	-0.00275	0.917

TABLE 6. Coho smolt production per female spawner. The table is divided into pre- and post-logging years.

	brood year	number of females	number of smolts 1.	2.	total	smolts/female
PRE-	71	75	1115	1444	2559	34.1
	72	75	1214	874	2088	27.8
	73	66	1247	1068	2315	35.1
	74	69	1995	935	2930	42.5
	75	55	1625	778	2403	43.7
POST-	76	51	3868	668	4536	88.9
	77	56	2862	991	3853	68.8
	78	176	3576	396	3972	22.6
	79	71	3719	622	4341	61.1
	80	43	2847	530*	3383	78.7

*preliminary

The utility of using measured smolt production from one system to index that of others would be considerably reduced if land use is changing within any of the indexed or indexing systems. Smolt production in Carnation Creek has changed markedly since the beginning of logging in the watershed, as shown by the smolt output per female spawner time series (Table 6).

After the beginning of logging in 1976, the ratio is not only greater but also more variable. It is not well understood how much of the changes observed in smolt production are due to logging-related effects as opposed to climatic variability, but it is clear that the carrying capacity of a creek is variable over time. In order to develop the potential of using indexed streams to predict smolt production from a region, it would be necessary to undertake a long-term inter-calibration of the major producing systems within the indexed region. It would also be necessary to increase our understanding of the production process itself, so that the confounding effects of land-use activities and climatic variability could be separated and corrected for.

While the problem of quantifying the long-term average smolt production from a stream appears tractable, the problem of elucidating the inflection point of the escapement-smolt curve is less well understood. There are several reasons for this. Egg mortality and early post-emergence mortality for Carnation Creek coho are not dependent on density but on hydrological and physical conditions in the stream (Holtby and Hartman 1982). Growth, on the other hand, is strongly density dependent. This coupled with a strong size dependency of first winter survival on fish size means that smolt output is buffered against variability in escapement and egg survival. As yet, we do not know how much variation in escapement and egg survival can be compensated for. While predictive relationships that relate production at any life stage to physical and biotic factors can be obtained, the result is an escapement-smolt relationship whose inflection point is determined by several independent random variables. Furthermore, "optimal" stock productivity would appear to be achieved at very low escapements. The danger in this is clearly the risk of allowing escapements to drop so low that the population is at risk of a "bad" year at some life history stage. This could drive the population below the inflection point, and under regimes of high exploitation, it might never recover.

Carnation Creek coho may be in just such a precarious position now. Smolt production has remained high despite variations in escapement of 43 to 176. This has been possible only because of the strong density dependence of growth over the first summer and the inverse size dependence of first-winter mortality. Increasing egg mortality due to the deterioration of the spawning gravel, coupled with a severe winter and low escapements in 1984, might lead to emergence so low that the density-dependent growth function saturates and the compensatory ability of the fish to grow is exhausted. The consequence of this would be a measurable decline in smolt production. A manager looking at the smolt output of the last few years might conclude, however, that the current exploitation rate of about 80% could be sustained on a long-term basis, since production has remained constant. Such a conclusion, for an unpredictable stream environment like Carnation Creek, is probably quite mistaken.

3. Intraregional Variability

Four creeks in the Barkley Sound region, in addition to Carnation Creek, have been sampled in late summer since 1972. We have used these data to examine the between-stream covariation in the abundance of coho salmon and of cutthroat and rainbow trout. Three of the four additional creeks have coho populations. Useless and South Pachena creeks have been sampled from 1972 to present. Sampling in Frederick's Creek was interrupted in 1978 and ceased permanently in 1979 owing to beaver activity. Cutthroat trout are found in Useless and Ritherdon creeks and in a side tributary of Carnation Creek called "tributary C". Rainbow trout are found in South Pachena Creek. The creeks have been sampled for trout from 1972 to present (Andersen 1983, 1984). Prior to analyses, the data were all converted to abundance per metre of stream and then expressed as standardized normal deviates (z-scores).

For 0+ coho (fry of the year), there is some similarity in the variation of the standarized abundances from 1973 onward (Fig. 5). The similarity is not statistically significant, even if the years prior to 1973 are excluded. Nevertheless, from 1973 onward, the patterns in all of the creeks are similar: an increase in the populations from 1973 to 1975, a four-year period of near average and constant population abundances, marked increases in abundances during 1979 and 1980, and in the last two years general declines. It is clear, however, that although the general variations are roughly synchronous and there does appear to be a general pattern when all of the creeks are considered together, no one creek would be particularly useful as an index of population levels in the others. Year-to-year variability of trout populations is more erratic than that found in coho (Fig. 6), and there is little evidence of similar patterns, either within the trout or between the trout and the coho.

In addition to population levels, we have examined the covariation of body size between the various populations of coho and trout. As with abundances, fish fork lengths were converted to standardized normal deviates prior to comparison. Weights were not used because of incomplete data.

As with abundances, there are suggestions of a common pattern in the variation of coho lengths of the four creeks over time (Fig. 7). Although there are considerably fewer outliers in these relationships than there were in those of the abundances, it is doubtful that there is statistically significant similarity between the time series, although this has not been explicitly tested. The covariation of trout sizes also shows some indications of similar patterns between streams (Fig. 8). There are also some indications that the trout and coho sizes were increasing throughout the 1970's, but may now be declining again. If the data for trout and coho are pooled, there is a significant correlation between standardized size and time for the period 1972-1980.

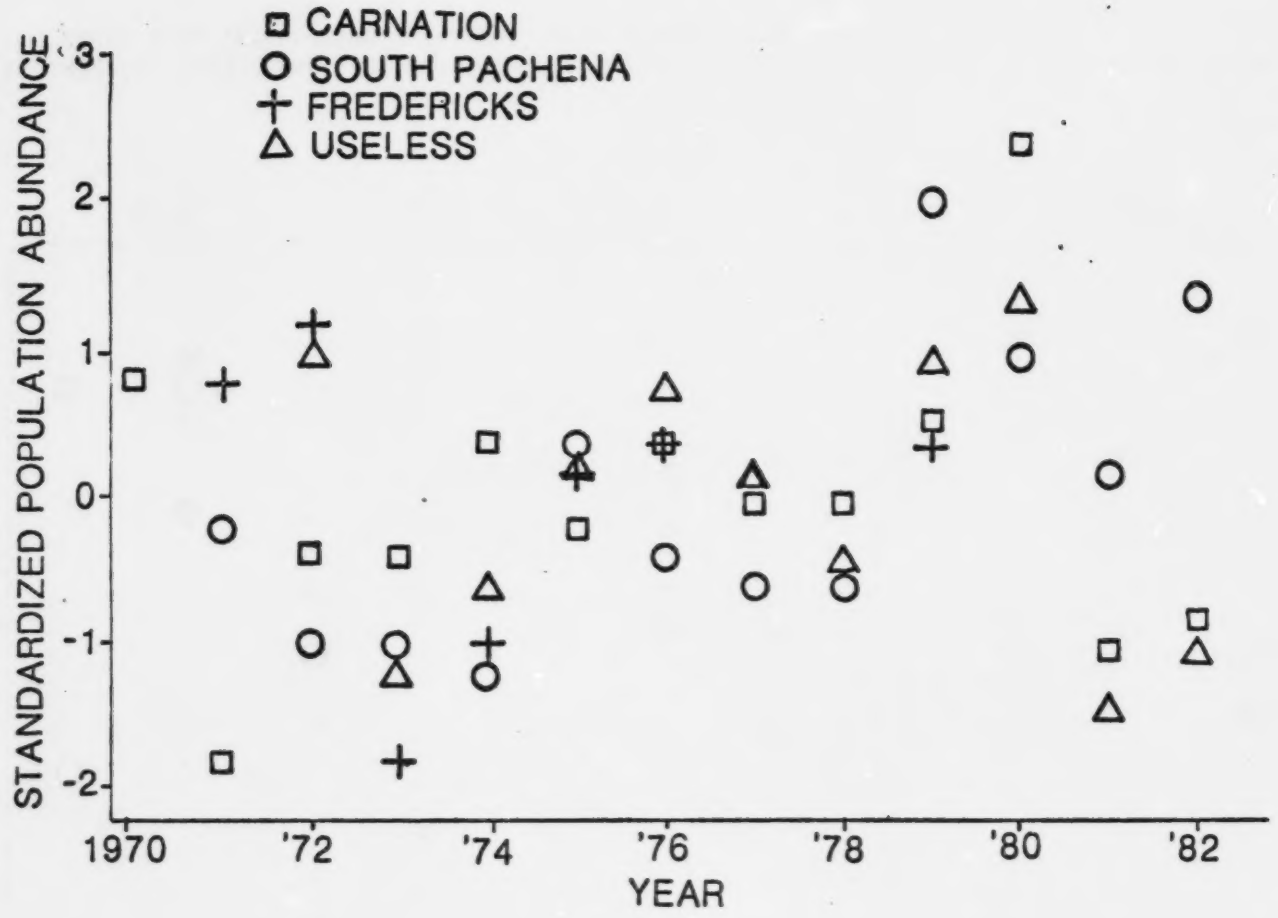

Fig. 5. Standardized normal deviates of late summer coho abundance in four streams of the Barkley Sound area versus time. The data were standardized within streams.

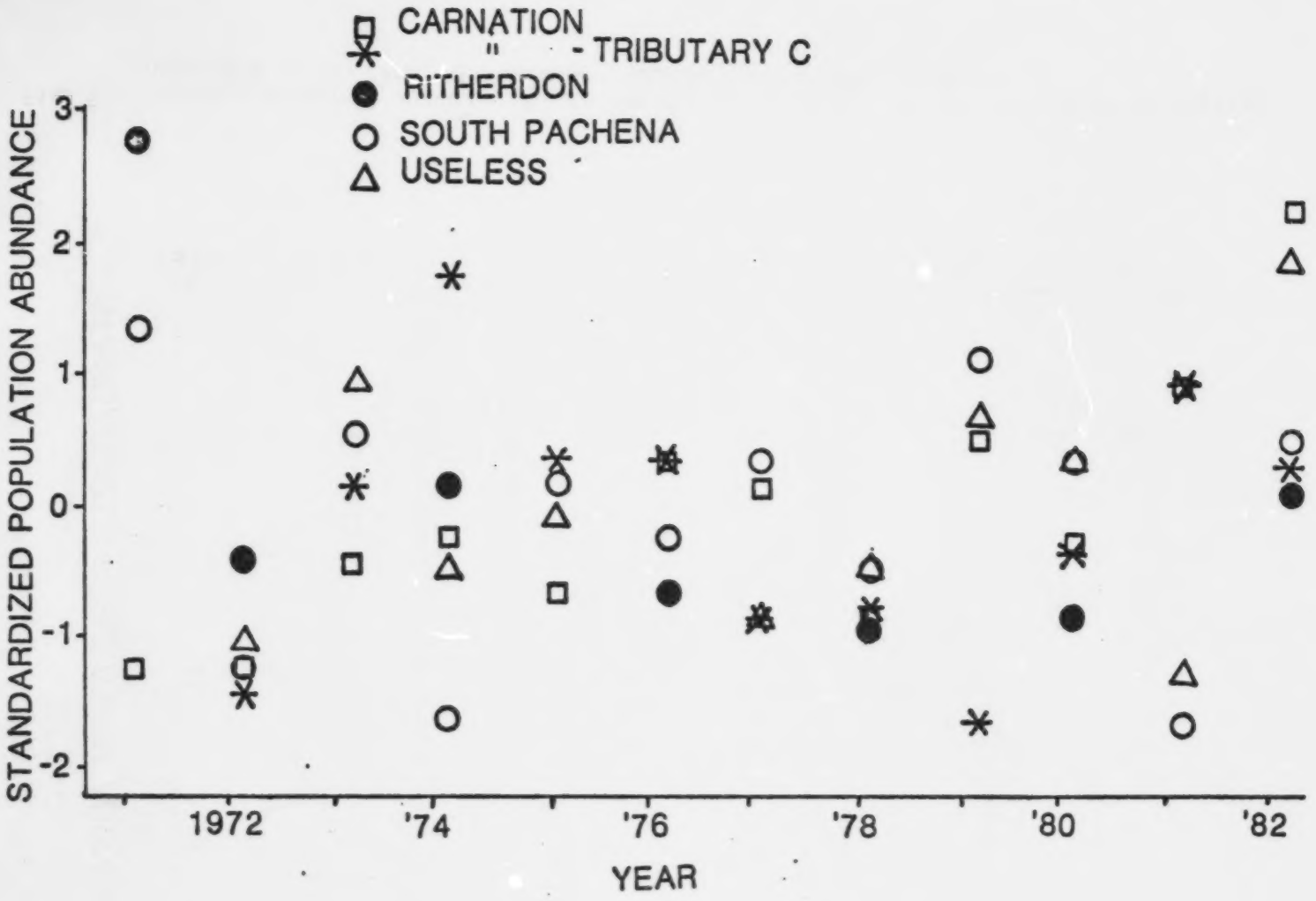

Fig. 6. Standardized normal deviates of late summer trout abundance in four streams of the Barkley Sound area versus time. The data were standardized within streams.

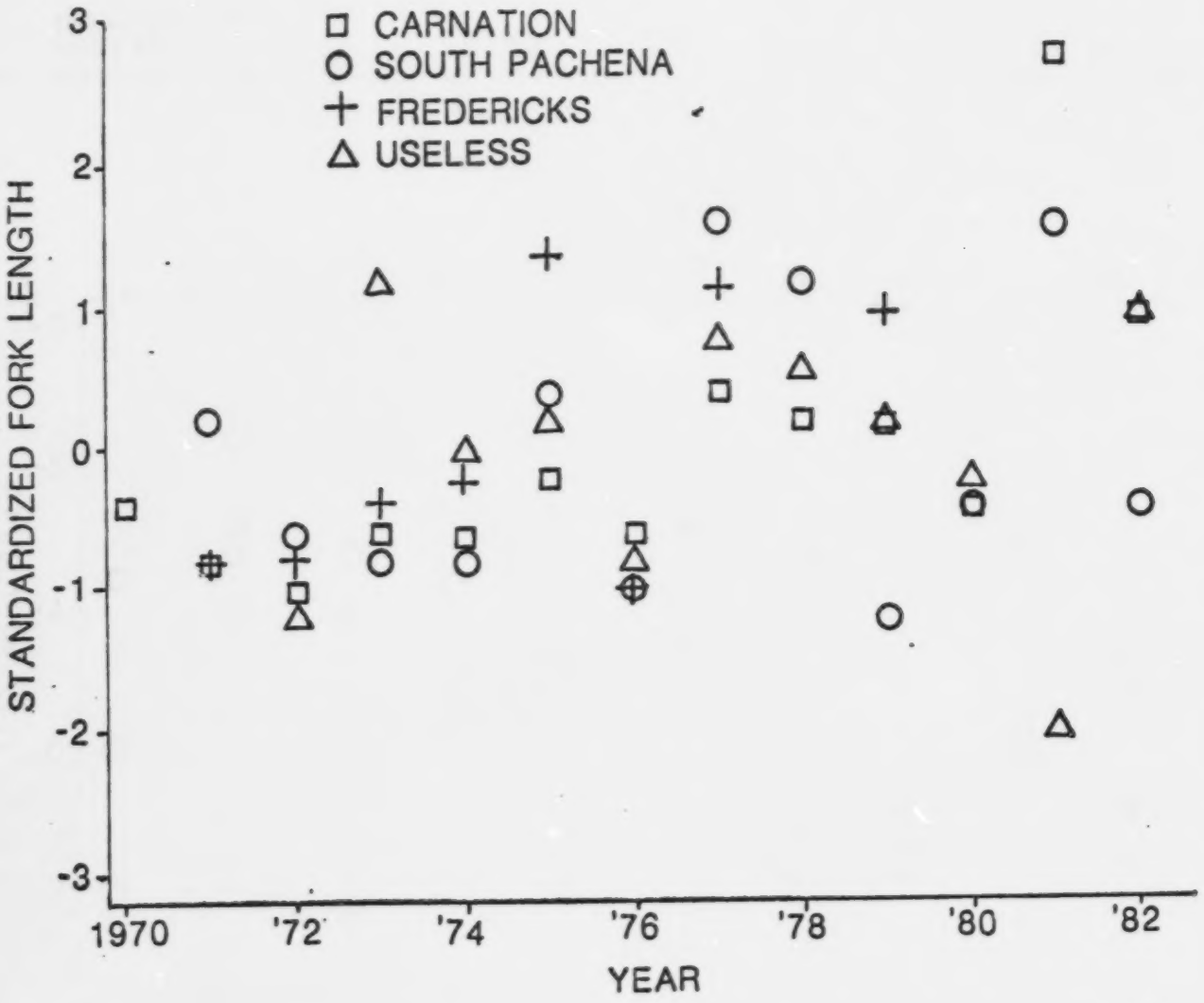

Fig. 7. Standardized normal deviates of late summer coho fork length in four streams of the Barkley Sound area versus time. The data were standardized within streams. Stream symbols as per legend for Fig. 5.

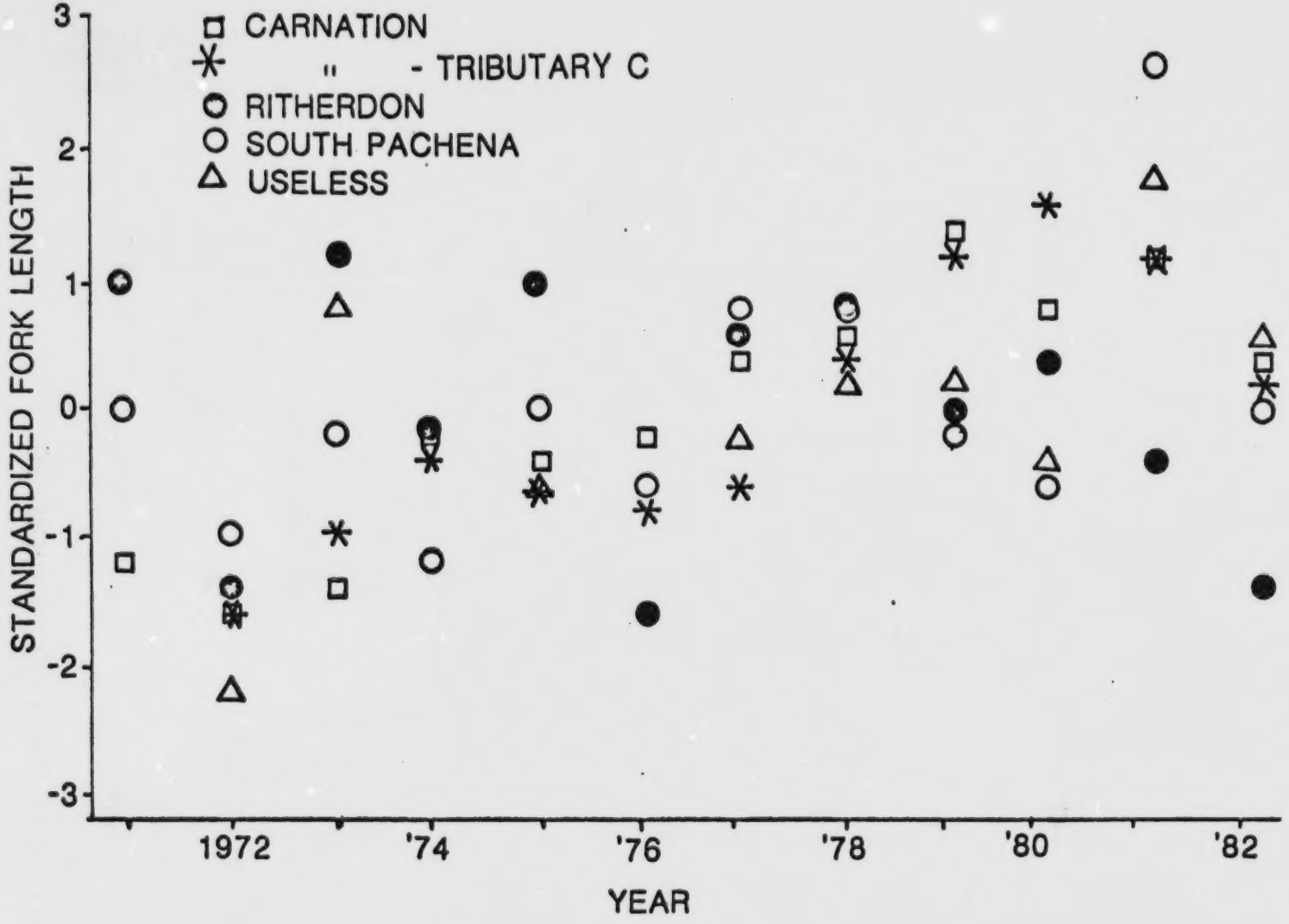

Fig. 8. Standardized normal deviates of late summer trout fork length in four streams of the Barkley Sound area versus time. The data were standardized within streams. Stream symbols as per legend for Fig. 6.

We have also used the data to briefly examine possible within-creek covariation between age groups. If population levels are caused primarily by escapement or by mortality early in the life history, then we would expect there to be correlations between the abundances of fish of the same cohort in successive years. Alternatively, if the observed covariation was largely due to variations in the mortality rates of juveniles, then we would expect a correlation between the abundances of different age groups within the same year.

Yearling coho are sufficiently abundant for analysis only in Carnation Creek. Here there is a highly significant correlation ($r=0.829$; $p<0.01$) between the abundance of 0+ and 1+ fish. The correlation is near-zero if 1+ abundance is lagged by a year ($r=0.158$; $p>0.1$). For Carnation Creek coho, at least, variation in the abundances of the two age groups are synchronous only within years and not within cohorts. We infer that variations in escapement (or in early mortality) have not determined variations in juvenile abundance. [Since we know the escapement in Carnation Creek, this lack of dependence can be demonstrated directly (Holtby and Hartman 1982)].

For trout the data suggest a somewhat opposite conclusion. There are sufficient numbers in the 1+ and 2+ age groups to allow comparisons within all streams. In the unlagged comparisons, correlations are mostly close to zero, with one exception (Carnation Creek), where the positive correlation is significantly different from zero (Table 7). In the lagged comparison, several of the correlations are significant and positive (Table 7). This suggests that, in at least some populations, the abundances of age groups are determined by the initial cohort size. If that could be estimated, a non-trivial task, then subsequent abundances of juvenile fish could be estimated.

In summary, there is suggestive evidence from our data that abundance and size of juvenile salmonids vary synchronously within a geographic region. For coho, age group abundance is correlated without a lag, indicating that some mortality factors are operating on both age groups simultaneously. Changes in escapement do not appear to be important to juvenile abundance, at least over the range in escapements observed. For at least some trout populations, initial cohort size is important in determining abundance in subsequent years. Whether cohort size is a function of the size of the breeding population or of egg survival (or both) is unknown.

The evidence for common patterns of variation is only suggestive, and could well be due to chance alone. However, we would argue that the similarities in the time series are sufficiently apparent to the eye that they cannot be dismissed, offhand, without more detailed and comprehensive studies. Given the relative ease with which juvenile abundance estimates can be generated compared to fence counts of smolts or adults, the investigation of late summer juvenile abundance as a means of indexing overall stock abundance in a region should be given considerable priority.

TABLE 7. Correlation between the standardized normal deviates of late summer population abundances for 1+ and 2+ cutthroat trout and, in South Pachena Creek, rainbow trout. For the non-lagged correlations, comparisons are made within the same year. For the lagged correlations, comparisons are made between the 1+ abundance in year i and the 2+ abundance in year i+1. Probabilities are for the two-tailed test with the null hypothesis of r=0.

Creek	non-lagged		lagged	
	r	prob.	r	prob.
Carnation - trib C	-0.362	>0.1	0.355	>0.1
Carnation - mainstem	0.837	<0.01	0.417	>0.1
Ritherdon	0.357	>0.1	0.954	<0.01
Useless	-0.495	>0.1	0.640	<0.1
South Pachena	0.095	>0.1	0.638	<0.1

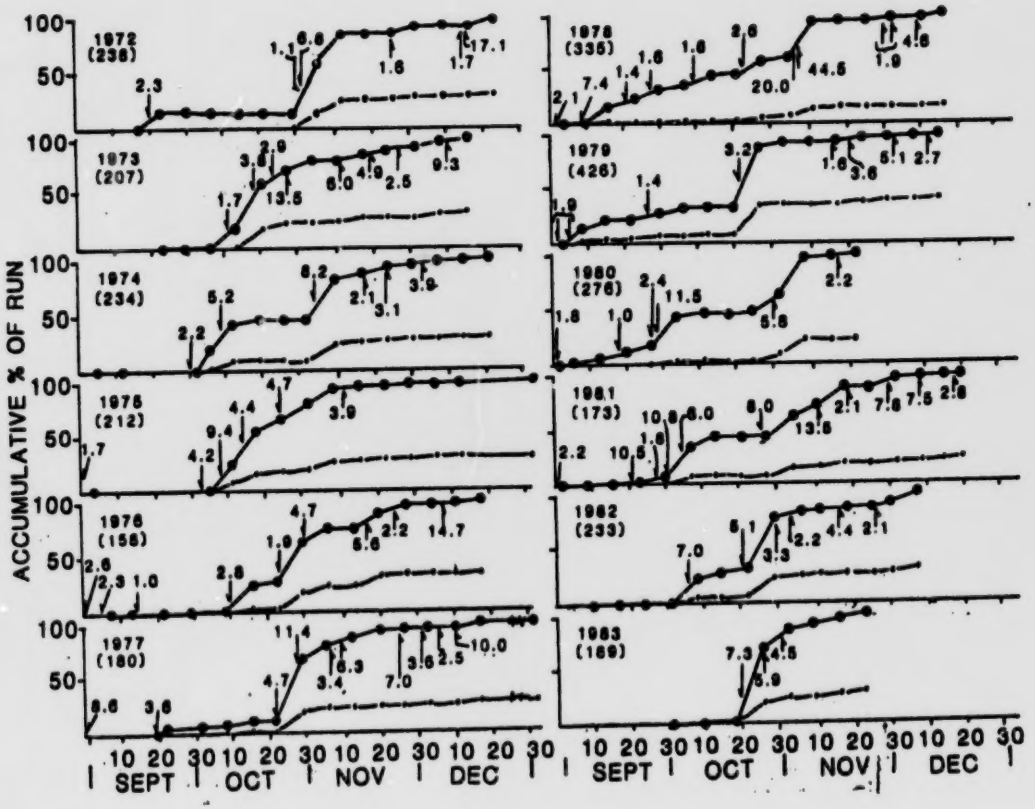

Fig. 9. Accumulative percentage of the coho run into Carnation Creek for the years 1972 to 1983. The solid line indicates the percent of the total run and the broken line indicates the percent of females. The total number of fish for the year is given in parentheses under the year. The arrows along each line indicate the first time that each freshet reached to maximum flow ($m^3.sec^{-1}$). In all years, except 1972, 1976 and 1980, the dates that maximum flow first reached or exceeded 1.4 $m^3.sec^{-1}$ are given. In some cases, maximum flow values, day by day, may have continued to rise much higher after the first value given.

4. Pattern and Timing of Coho Escapement

All coho returning to Carnation Creek are enumerated at a permanent fish fence near the creek mouth. Twelve years of data are now available (Andersen 1983, 1984).

Fish have first been observed at the fence as early as September 2 and as late as October 1 (Fig. 9). In most years some fish have been seen in the first week of September. Jacks predominate the September escapement and comprise 20-70% of the total. Most large adults enter the creek after October 1, and virtually all of the fish have entered the creek by the second week in November.

Entry of both jacks and large adults is dependent on freshets. In years with continuous fresheting (1973, 1975, 1978), the entry of fish is continuous. In years with infrequent freshets, entry is conspicuously stepped. In one year (1983), the creek did not freshet until late October, and 70% of the total escapement entered within the space of several days after the initial freshet. It seems reasonable to assume that returning adults require high water to enter shallow coastal streams, and as they arrive, they station themselves off the creek mouth waiting for a suitably high flow. In Carnation Creek, the required flow is somewhere in the order of 1 - 2 $m^3.sec^{-1}$.

The erratic pattern of entry to Carnation Creek and the short duration of entry would appear to rule out the use of escapement data in real-time management of the fishery. The evidence, which we have presented previously, indicates that the terminal net fisheries on chum and sockeye in Barkley Sound are coincidentally capturing significant numbers of Carnation Creek coho. Since these fisheries take place throughout the summer, but have ceased before the fish enter the creek, escapement data would be of no use in real-time management.

Since flow patterns within a region should be very similar, the timing and pattern of escapement on one small stream should be representative of other small streams in the region. This assumes, of course, that the timing of oceanic migrations is similar for all populations within that region.

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AN OVERVIEW OF SALMON ESCAPEMENT ENUMERATION METHODS USED BY THE FRASER RIVER, NORTHERN B.C. AND YUKON DIVISION

by

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INTRODUCTION

Each year, estimates of the number of salmon spawning in British Columbia and Yukon Territory streams are submitted on standard forms to the head office in Vancouver. These forms then enter the escapement files, and the data constitute the "official" estimate of the number of salmon spawning in each stream. The escapement information serves several purposes in fishery management, including forecasting the strength of subsequent returns, reconstructing past runs, comparing actual escapements with preseason goals and development of stock-recruitment models. It is also used by habitat managers in assessing the effects of environmental alterations, and by those involved in developing enhancement proposals.

As well as post-season estimates of the number of salmon on the spawning grounds, the magnitude of some of the largest stocks or groups of stocks is monitored as they migrate through principal fishing areas. This in-season abundance information assists managers in determining when to open and close fisheries to achieve escapement goals.

The following comments apply specifically to the Fraser River (excluding sockeye and pink salmon, which are managed by the International Pacific Salmon Fisheries Commission), other streams of Statistical Areas 28 and 29, the northern B.C. transboundary rivers (particularly Taku and Stikine) and the Yukon River. However, because the approach to salmon escapement enumeration by the Department of Fisheries and Oceans is similar throughout British Columbia, the methods outlined here are largely representative of the situation elsewhere in the province.

IN-SEASON

Test fishing is the primary method used to assess the abundance of salmon migrating through an area during the fishing season. Within the lower Fraser River, the Department of Fisheries and Oceans operates gillnet test fisheries annually to estimate the abundance of chum and chinook salmon. To provide consistency and enable meaningful year-to-year comparisons, an attempt is made to standardize as many variables as possible including net

dimensions, fishing site, duration of set, timing of set in relation to tides, and the fisherman undertaking the test fishing.

Test fishing for Fraser River chums has been conducted since the early 1960's. The index is used to assist in determining the timing of commercial gillnet fisheries in the Fraser River Area. There is a rough correlation between the cumulative seasonal test fishing index and the number of chum salmon subsequently recorded on the spawning grounds. This relationship would undoubtedly improve if more accurate spawning estimates were available.

A chinook test fishery in the Fraser River, initiated in 1980, operates annually from April to October. It provides a means for helping to assess the effectiveness of various conservation measures for chinook salmon by monitoring the return of adults to the river. As more intense management of the Indian food fishery develops, an in-season abundance estimate of chinook will become increasingly useful in providing the basis for management decisions, which take into account the requirements of specific stocks or groups of stocks.

POST-SEASON

The majority of escapement estimates are made by fishery officers of the Department who, simultaneously, have other major enforcement or fishery management responsibilities. The effort dedicated to escapement surveys is largely a function of the time available to the officers responsible for each geographical region and, therefore, varies considerably from area to area and from year to year in the same area. This inconsistent approach undoubtedly affects the reliability of the data.

In a few areas, other techniques, such as counting weirs or mark-recapture programs, are used to assess spawning abundance, although these methods are often temporary and done in conjunction with programs with different objectives. Usually the Management Biology Unit is responsible for undertaking such programs.

The following is an outline of the methods used in this division.

1. Visual Estimates

Visual counting is the commonest method of estimating the number of salmon on the spawning grounds. The estimates are generally made by fishery officers on foot, by boat or by air, with the method used dependent on the nature of the stream and stocks and on available funding. The accuracy and consistency of the estimates are highly dependent upon factors such as stream clarity, accessibility, distribution of spawning fish and time spent on surveys. There is no prescribed regional training program for salmon enumeration; consequently, a great deal of variation in the methods used by fishery officers exists. Some officers apparently record only the number of salmon actually seen whereas others expand the observed numbers to what they feel is the total spawning population. The expansion factors used are rarely recorded. Visual estimates are considered to be relatively

inaccurate, although experienced observers under ideal conditions can probably make reasonably accurate and consistent estimates of some species such as chinook. In spite of the obvious shortfalls in the techniques, the combined estimates in the Fraser for chinook and chum salmon tend to reflect the pattern previously observed in test fisheries. Probably, in general, the level of accuracy and precision is sufficient to indicate if the abundance of spawning salmon is low, medium or high.

2. Counting Weirs

Counting weirs have been operated annually since 1959 at the outlet of Tahltan Lake (Stikine River System) and since 1976 on the Klukshu River (Alsek River System). The Tahltan weir is used to enumerate a run of lake-spawning sockeye, which was once considered to be the only major sockeye stock contributing to the Stikine fishery. Recent application of stock separation techniques to Stikine sockeye using scales and parasites enables calculation of the magnitude of the newly discovered mainstem population by using the proportion of Tahltan: mainstem in the commercial fishery and the Tahltan escapement. Thus, the usefulness of the Tahltan escapement data is increased.

The Klukshu weir enumerates populations of chinook and sockeye which serve as indicators of the abundance of these species in nearby streams. It is assumed that these other stocks follow the same trend as Klukshu, although no investigations have been undertaken to confirm this.

In addition to the two weirs described above, several temporary weirs associated with hatcheries in the Fraser River have been used recently. Their main purpose is brood stock capture, although in some cases they may be useful for obtaining escapement estimates on a consistent basis. Other weirs have been temporarily installed on various tributaries of the Fraser River from time to time, usually in conjunction with programs having broader objectives, with varying degrees of success.

When operating properly, counting weirs can provide virtually exact counts of fish entering streams. However, most weirs used in the Fraser River watershed have been washed out by floodwaters prior to completion of the salmon runs, thereby limiting their usefulness. Counting weirs also tend to be expensive to operate owing to the necessity of having personnel on site at all times.

3. Mark-Recapture

In the Fraser River, several mark-recapture programs to estimate spawning escapements have been conducted over the past two decades. In some cases, the major objective was to develop a reliable measure of spawning escapements, whereas in other cases, spawning escapement estimation was undertaken as an adjunct to other programs. The most comprehensive effort was a disc-tagging program on major Fraser River chum stocks conducted for about a 10-year period in the 1960's. In the late 1970's, part of the program was reinstated for several years before being terminated again. Mark-recapture estimates of escapement have been conducted in a few areas

in conjunction with spawning ground recovery programs for chinook and coho bearing coded wire tags. These programs generally continue for only three or four years at each site and are therefore of little value in providing comparative escapement counts over the long term.

Populations of chinook and chum in the mainstem of the Yukon River have been estimated during several years by tagging salmon captured below the commercial fishery in the vicinity of Dawson and later recovering tags from the fishery. This also enabled calculation of exploitation rates and gross escapements from the fishing area.

One of the main problems with these mark-recapture programs is their relatively high cost. Because of this, funding has been sporadic and the desired continuity has not been maintained.

FUTURE PROSPECTS

The deficiencies in Department of Fisheries and Ocean's escapement enumeration system have been recognized for some time and various suggestions have been made for improving the accuracy and precision of the estimates. Part of the problem stems from inadequate recording of the methods used to derive the estimates and lack of confidence limits associated with the estimates. In an attempt to improve the recording of the relevant information and possibly help standardize the methodology, a new form to be used by officers in the field was tested in a few areas in 1983. The information from these field forms is used to derive the total escapement estimates, which are recorded along with other pertinent information on another new form for annual escapement estimates.

Access to salmon escapement data should be improved markedly when a new computerized data base comes on line. At present, users must summarize information manually using the escapement files.

There are currently a number of proposals to enumerate some of the relatively large populations of salmon by more accurate methods than are presently in use. These methods, which include fence counts, mark-recapture, frequent aerial surveys and dead pitches, would require significantly greater expenditures of funds to achieve the desired results. To be of real value, the programs would require assurance of on-going support funds in order to provide comparative counts on an annual basis. Proposals of this type are currently being reviewed to determine their relevance and effectiveness in meeting our salmon escapement requirements.

ESCAPEMENT ESTIMATION IN THE MANAGEMENT OF FRASER RIVER SOCKEYE SALMON

by

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ABSTRACT

Sockeye stocks of the Fraser River are enumerated on the spawning grounds to obtain basic production and reproductive stock data. This enumeration is the last of a series of escapement estimates which commence as the sockeye enter the lower Fraser River. Gross escapement estimates become a basic input of the fishery management program. Integrated escapement estimation programs enable the fishery manager to adjust in-season the exploitation rate to match gross escapements by stock to the preseason goals. The optimum net escapement, the forecast return and expected Indian fishery removals provide data on which these goals are established.

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INTRODUCTION

Management of Fraser River sockeye salmon is geared to obtain actual gross escapements, by stock, near the preseason goals established by spawner-recruit analysis, the individual year forecast of return abundance and the expected Indian fishery removals upstream. This process normally requires extensive in-season regulatory action to adjust exploitation rates and, thus, achieve the desired mix of escapements. To obtain needed information on actual escapements, the Commission has developed an integrated estimation procedure. It begins as the fish migrate through the lower Fraser River and terminates with the collection of data on the spawning grounds. Data from the lower river gross escapement estimates, upriver index counts and spawning ground arrivals are continuously updated and analysed for management of the fishery. Spawning ground programs evaluate the success of migration and reproduction. The information obtained is used to: a) develop in-season management strategies, b) complete a post-season analysis of the year's return, c) forecast the following year's return, d) predict the next generation of the cycle being enumerated, and e) analyse population structure and dynamics of production. Long-term management objectives and annual escapement goals are developed on a stock-by-stock basis from estimates of total catch and spawning ground escapement. Hence, the process of escapement estimation provides the data required in all facets of Fraser sockeye salmon management.

In this paper, I discuss the Commission's current techniques for estimating escapement and expand upon the data collection process. A discussion of the use of these data for in-season management of the Fraser River sockeye fisheries, in spawner-recruit analysis, and in forecasting concludes the presentation.

ESCAPEMENT ESTIMATION - A PROCESS

Estimation of the gross escapement for those summer-run sockeye stocks which immediately enter the Fraser River upon arrival begins in the lower Fraser River. Acoustic monitoring of the migration at Mission, B.C. provides daily gross escapement estimates. Daily escapement by stock is obtained by combining these data with racial composition estimates (Henry 1961) from test fishing samples. Late-run sockeye delay in Georgia Strait before migrating upstream. Therefore, acoustic estimation of the escapement occurs near the end of the harvest period. Escapement to Georgia Strait is estimated with CPUE methods.

Commission staff monitor the migration of summer and late-run sockeye as the fish pass through Hell's Gate fishways and in terminal area Indian fisheries. Index counts are, at times, conducted immediately downstream of selected spawning areas. Enumeration on the spawning grounds is usually the last in a series of escapement estimates.

Commission spawning ground enumeration techniques have evolved to satisfy the data needs of the fishery manager and to suit the nature of sockeye salmon spawning populations. For the most part, sockeye occur in the larger streams of the Fraser watershed and, moreover, occur within well defined sections of those streams. There are approximately 25 major, and a similar number of minor, stocks of sockeye in the Fraser River watershed, most of which are closely associated with major lakes where the fry rear for one or, occasionally, two years. Sockeye stocks occur as high density, large populations in restricted areas. Such spawning distributions are possible because sockeye are dependent on the stream environment only for incubation. Little if any rearing of sockeye fry occurs in the spawning streams; hence, high densities are supportable. Commission spawning ground enumeration techniques take advantage of the large populations and restricted dispersal. Visual techniques of estimation have generally produced poor quality data on larger populations. Therefore, mark-recapture programs are used extensively and provide estimates that have narrow confidence limits.

GROSS ESCAPEMENT ESTIMATION

Sockeye salmon escapements are monitored daily during closures in the Fraser River fishery. Test fishing above Steveston and near Whonnock (Figure 1) provide index catches and CPUE data. Summed daily CPUE during the escapement has been related to the corresponding accounted upstream escapement for the years of record to obtain index values which are used to convert daily CPUE into estimates of escapement. Species composition data and sockeye scales for racial analysis are also obtained from these operations.

The daily escapement past Mission has been monitored acoustically since 1977. This location (Figure 1) is above the commercial fishery boundary but below the intense Indian fisheries. Echograms are obtained in transecting from shore to shore. From these, we obtain target counts by depth interval and hour for fish density data. Rate of travel is estimated by calculation of target duration in the acoustic field during stationary sounding periods. Density and rate of travel data combine to provide hourly and daily estimates of fish migration past the site. Non-salmonids are estimated by baseline studies at times that salmon abundance is low owing to removal by the commercial river fisheries. The racial composition of test fishing catches is applied to the acoustic estimate to provide daily gross escapement by stock. These estimates are available within a few hours of completion of the acoustic sampling and enter immediately into the fishery analysis.

Migration route index counts, primarily at Hell's Gate fishways, provide information on travel rates and on removals by the Indian fishery between Mission and Hell's Gate. Daylight counts on one bank are adjusted to obtain an estimate of daily passage. These data are made available to the manager after each day for analysis and use in the current decision-making

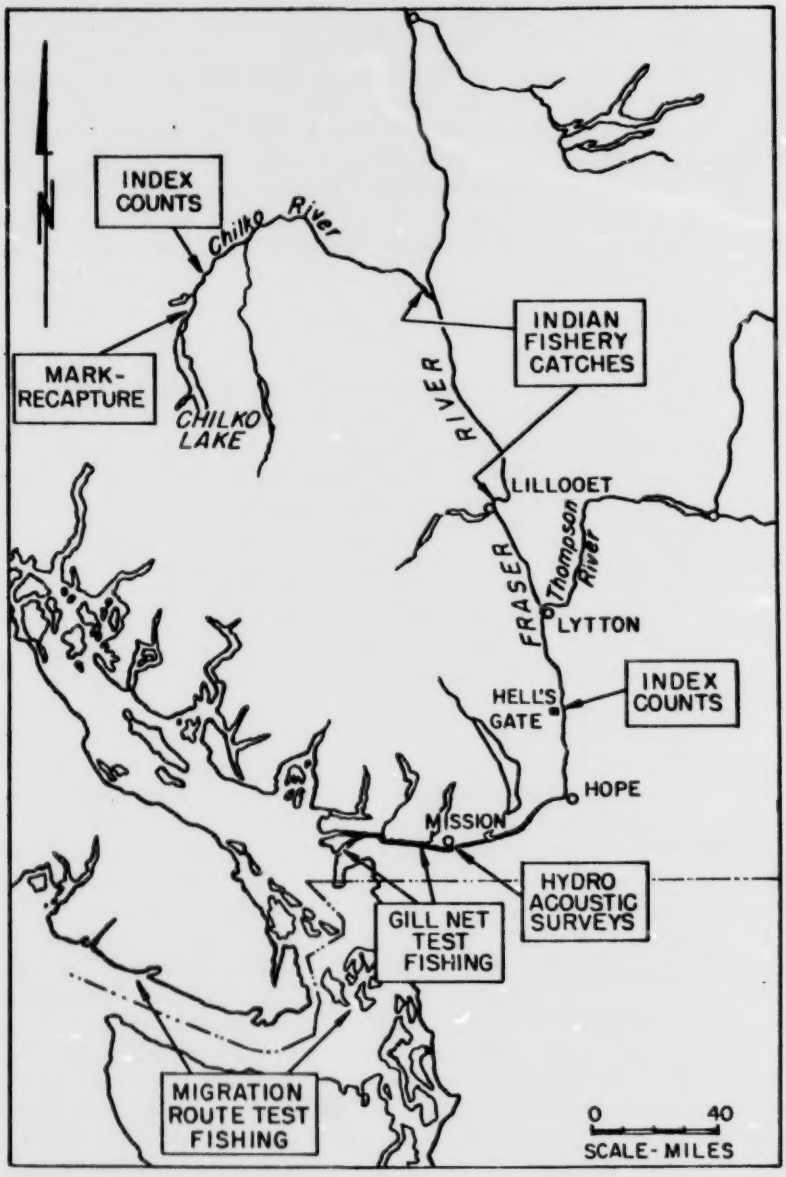

Figure 1. Escapement estimation and monitoring sites for Fraser River sockeye (Chilko River sockeye example).

process affecting fishing time and, thus, the following closed period escapement.

Catch per unit of effort data from terminal area Indian fisheries (Figure 1) related to gross escapements several days earlier have proven of value in determining speed of migration (Killick, 1955) and escapement abundance. In-season monitoring of these fisheries aids in the analysis of current Indian fishery exploitation, of migration losses and delays, etc. which may affect decisions pertaining to escapement goals for later-timed stocks. It is clear that accurate Indian catch data are required so that the manager may evaluate properly the gross escapement required to meet net escapement goals.

SPAWNING ESCAPEMENT ENUMERATION

Extensive planning is required for escapement enumeration programs, particularly in the establishment of data objectives and priorities. Annual Fraser sockeye enumeration programs provide population size by sex, spawning success and biological samples. Mark-recapture and visual surveys of the population are the usual methods of estimating the spawning population. While the typical enumeration program does provide some information on time of arrival, these estimates are not precise. Therefore, for some major stocks the Commission conducts daily index counts downstream of the spawning grounds (Figure 1, Chilko River sockeye used as an example). Management of spawning channels requires control of access and limitation of spawners to optimum density and timing. Electronic counters have been used to count fish entering these controlled facilities.

In addition to data requirements, population size and dispersal of the spawners enter into the planning of enumeration programs. Normally, sockeye spawning populations in excess of approximately 20,000 fish are enumerated by mark-recapture techniques. Escapements under this level or highly dispersed populations are usually counted visually and estimated using expansion factors determined from years with both mark-recapture and visual estimates. Local conditions may vary the methods used on some stocks. For instance, turbidity limitations may dictate mark-recapture programs on stocks down to 5,000 fish. Deviation of actual production and escapement from preseason forecasts results in some variation from abundance criteria. From 1980 to 1983 the smallest population estimated by mark-recapture techniques was 9,000 spawners, while visual estimates were used on populations up to 66,000 fish (on a remote stream). An average of nine individual sockeye salmon mark-recapture programs were carried out, estimating 85% of the spawners annually.

Mark-Recapture Techniques

The decision to conduct a mark-recapture program must be made some months in advance of the necessary workdate. Materials and manpower are allocated within the framework of the total enumeration program. Nets, tags, boats and a multitude of materials are committed for the period of tagging and recovery work. Crews are selected with experience in tagging programs and familiarity with the spawning grounds. Most importantly, funding for the entire program must be budgeted some time in advance. No comprehensive enumeration program can occur without this long range planning process.

Adult salmon spawning escapements cannot be considered "closed" populations, but are characterized by the flux of spawners arriving over a given time frame. The duration of arrival (days) may well exceed the average residency time of the spawners. In this situation, the entire population is not present at any specific time that would allow for a short tagging period and a short recovery period. Rather, the partially "open" nature of the population requires specific techniques to insure estimation of the entire population. We stress tagging and recovery in proportion to abundance. However, tagging normally is not extended over the period of arrival due to cost considerations and to the difficulty in the allocation of tags. Either the daily number arriving is not known or new arrivals are not accessible by the tagging crew. Therefore, tagging in proportion to abundance is rarely possible. Tagging normally extends over a two to three week period on larger populations, and may access fish which arrive over a longer period owing to spatial distribution of tagging effort and to the capture of fish schooled prior to dispersal. If the arriving fish delay for a significant period before spawning, accessing these schools may provide approximately proportional tagging. Often representatives of a major portion of the arrival can be tagged by this method. The criteria for success are many: Monitoring of arrival, delay behavior and access (seining locations). In other cases a migration route location is selected. The major segments of the arrival are tagged but possibly at variable tag ratios.

Actual tagging rates vary with fish availability and population size but, typically, a goal of 1% of the population is set. Often one-half of the tags are allocated to females and one-half to males and jacks.

Inability to accurately estimate the proportion of the daily arrivals which are tagged dictates that most Commission recovery programs be geared to a long period of dead recovery work. The strategy normally adopted is to collect and examine all the dead carcasses in specific areas of the spawning grounds. Frequent coverages of these areas near the peak dying period are required to maintain a consistent rate of recovery. The program objective is to recover carcasses in proportion to the sequential die-off numbers.

Mixing of tags in the population may not be random over time and often this translates to unequal marked:unmarked ratios between areas within the stream. To avoid bias, recovery throughout the spawning area in approximate proportion to population size then becomes quite important. The fraction sampled in the dead recovery effort varies from 5% to 30% or more of the total population. Maintenance of significant recovery levels has been promoted to ensure a thorough coverage of all stream areas during the spawning season. Adequate sample size is required for a narrow confidence interval. While the population size does dictate the sampling fraction to some degree, the desired confidence interval is not the determining factor. Rather, dispersion of the population and physical access has much influence on the tag recovery. Budget constraints also determine manpower inputs and, hence, recovery fraction.

Extensively deteriorated carcasses as well as fresh dead fish are recovered and removed from the stream bed or, in some areas, are cut to insure no subsequent recovery. Tags are frequently missed in the recovery of

deteriorated carcasses due to a mat of Saprolegnia (fungus) covering the carcass and tag. Overenthusiastic workers also may become competitive in pitching carcasses and, hence, foresake care in examination for tags. These factors require that a repitch of carcasses be made to estimate the frequency of missed tags. Approximately 10 to 30% of the initially-sampled population is repitched.

Sockeye tagging and recovery rates may be adjusted to optimize the cost and statistical validity of the data. If feasible, small populations should be tagged at higher rates than large populations, and recovery rates should be higher as well to insure tight confidence limits on the estimates. The mark-recapture experiments conducted by the Commission in 1983 (Table 1) show typical ranges in tagging and recovery rates and in confidence limits (estimated by a binomial approximation model). Tagging rates varied from 0.65% to 2.88% while recovery rates were 6.9% to 48.3%. Confidence intervals were from 12.4% to 86.5% of the point estimate. Normally, sexes are separated in the estimation procedure which would enlarge the confidence intervals slightly.

Success of egg deposition is estimated by daily sampling of female carcasses for retained eggs. Weighting by the daily dead recovery of females provides a seasonal mean value. Fresh dead carcasses are further sampled for length, otolith and scale. The age of individual fish is obtained from an otolith since scale resorption invalidates scale age readings. Scales provide freshwater growth zone circuli counts and measurements and early marine growth measurements for racial analysis of commercial catch. Fecundity estimates are obtained periodically by sacrificing and sampling 50 unripe females taken from the peak period of entry at the spawning grounds.

Visual Surveys

Many Fraser sockeye stocks are small, with escapements generally under 20,000 spawners annually. Other stocks produce poorly on non-dominant cycles and therefore have small escapements. In these cases, mark-recapture techniques for spawner estimation are not practical due to the cost and statistical properties of the estimators. In other situations, poor access or lack of facilities dictate that visual estimates be used as an alternative to mark-recapture experiments. Visual counts may be made by float surveys, by foot or by air. Water clarity and light conditions should be optimal or as consistent as possible. These surveys are conducted at the hours of optimum light conditions to minimize reflection and to provide week-to-week and year-to-year consistency in the data obtained.

Visual counts of spawners are made periodically throughout the spawning period. Normally, a dead recovery effort is made as well. The peak live count plus the accumulated dead recovery and/or dead count provides a number to which is applied a factor relating this count to the total population. Visual surveys have been conducted along with mark-recapture experiments and weir counts for many stocks and years. Comparison of peak live counts to total population yields expansion factors for use on standardized visual counts. Confidence interval estimates for visual counts are related to the confidence interval for the mean expansion factor obtained in a number of experiments. An example would be experiments on Early Stuart sockeye streams.

TABLE 1. Mark-recapture estimates of the 1983 Fraser River sockeye with point estimates and 95% confidence intervals (C.I.)

SPAWNING GROUND	SEXES COMBINED									
	TOTAL TAGGED	TOTAL RECOVERY	TOTAL RECOVERY TAGGED	95% C.I. UPPER LIMIT	POINT ESTIMATE	95% C.I. LOWER LIMIT	UPPER LIMIT (%)	LOWER LIMIT (%)	% TAGGED OF TOTAL POPULATION	% RECOVERY OF TOTAL POPULATION
Chilko River and North End Lake	3,508	84,537	896	353,256	330,706	310,118	6.82%	6.23%	1.06%	25.56%
Upper Pitt River	300	2,179	52	16,443	12,380	9,628	32.82%	22.23%	2.42%	17.18%
Birkenhead	1,369	7,951	228	54,264	47,572	42,022	14.07%	11.67%	2.88%	16.23%
Seymour River (early)	400	4,104	55	38,794	29,394	22,985	31.98%	21.80%	1.36%	13.77%
Weaver Creek Proper	251	2,819	34	29,038	20,303	14,935	43.02%	26.44%	1.24%	13.72%
Stellako River	2,000	59,841	982	129,678	121,814	114,550	6.46%	5.96%	1.64%	48.32%
Adams River	2,552	30,428	382	224,583	202,833	184,018	10.72%	9.28%	1.26%	14.81%
Chilko Lake South End	347	3,673	23	83,088	53,272	36,997	55.97%	30.55%	0.65%	6.89%
						MEAN:	25.23%	16.77%	1.56%	19.56%

Fifteen experiments between 1952 and 1977 gave a mean expansion factor of 1.71 and a confidence interval of 1.55 to 1.87 or approximately ±10% of the estimate value.

Periodic live counts also provide time of arrival information if migration delays do not occur below the spawning grounds. Sampling for sex ratios, retained eggs, otolith and scale is conducted during a limited dead recovery.

Index Counts

Visual counts of migrating sockeye have been used to obtain timing curves and preliminary population estimates. These counts are normally conducted where major stocks have largely segregated from co-migrating stocks. Visibility and access determine the feasibility and selection of counting sites. Sites upstream of significant Indian fisheries are chosen. Fish must be migrating past the site in a relatively narrow band and exhibit consistent behavior to make visual counts effective. Usually only one bank has been counted but occasionally both banks or periodic checks on the opposite bank have been made. Two 15-minute counts per hour are obtained for 7 or 8 hours per day. The mean 15-minute count is expanded by a previously determined value to arrive at the daily estimate of passage.

At Chilko River (Figure 1), several years of counts at a location approximately 16 km below the major spawning area have produced an average index value of 123 (95% C.I. = 106-140); that is, average 15-minute count x 123 = daily population arriving. These estimates are too variable to reliably provide the population size. The method does, however, provide excellent estimates of the arrival curve if conducted throughout the migration. These arrival curves are superior to those obtained on the spawning ground since variable delays can occur immediately below spawning areas, lessening the integrity of the chronological order (Killick, 1955).

Total Counts/Recovery

Total counts are obtained at locations of restricted access using fences or electronic devices. Fishways and entrances to spawning channels are restricted-flow situations amenable to conductivity counter operations. In addition, weirs have been constructed immediately below spawning grounds to enumerate the population. Both techniques provide high quality numerical and timing data but generally at higher cost than visual estimates. The drawback to this method is that large populations may require extensive manpower or equipment inputs. Dead recovery work is required to obtain sex ratio, success of spawning data and biological samples.

Removal of carcasses from spawning channels provides a total count of spawners by sex. Success of spawning and fecundity data are obtained for precise estimates of egg deposition to evaluate incubation success.

Acoustic monitoring of the upstream migration by Doppler sonar has been investigated and will, undoubtedly, be extensively used in the future.

ESCAPEMENT ESTIMATION IN THE MANAGEMENT PROGRAM

The data obtained in the escapement estimation program are integral to the management of the Fraser River sockeye salmon fisheries. Actual escapements past Mission are the vital data the manager must have on which to base in-season management decisions for adjustment of the fishery exploitation rate. Timing curves and abundance estimates are used with scale data to estimate the stock composition of commercial and Indian catches. Spawner-recruit analyses and optimum escapement estimation are priority uses for spawning ground data. Jack sockeye abundance estimates, and scale and length data from spawning ground programs provide the data base for preseason forecasting. Each use of the escapement data demands a somewhat different form of the data and level of accuracy.

IN-SEASON MANAGEMENT

As the daily gross escapements by stock become available, they enter the data base for analysis of the fishery. Management of the summer-run sockeye fishery is dependent on the actual gross escapements. A sequential pattern of management is used where weekly fishery exploitation rates are calculated from catch and escapement data and applied to the incoming stocks for the following periods. Throughout the season updating of the exploitation rate estimates is necessary as variable regulations affect catches in the different fishing areas. Data from migration route test fisheries (Figure 1) along with catch data from distant fisheries and exploitation rate estimates provide the manager with the required data to simulate the impact of inside fisheries and to predict the short-term gross escapements under a range of fishing options. The overlapping arrival curves of the many stocks with significant production each season requires extensive manipulation of exploitation rate in-season to match the actual gross escapements by stock to preseason goals. Exploitation rates may vary greatly for different timed stocks but similar timed sockeye necessarily have similar commercial harvest rates.

Index counts obtained 5 to 6 days migration upstream at Hell's Gate reveal much about the speed of travel and removals by the Indian fishery. These data are used to adjust the gross escapement goals in-season to insure that net escapements are near the desired levels.

Sockeye arrival curves are generated from gross escapement, migration route test fishing and catch data. The arrival curves of early stocks provide information on timing which can be applied to the timing and run strength analyses for later arriving stocks. A key management objective is to properly evaluate the abundance of each stock sufficiently early in the arrival curve to take effective action to secure the proper gross escapement. Constant re-evaluation of timing, run size and gross escapement information is the key to management by escapement.

Arrival timing obtained from terminal Indian fishery catches and index counts below spawning grounds is used in the analysis of timing through the fisheries. Catch by stock is estimated for all commercial and Indian fisheries. The racial analysis is based on scale circuli counts and measurements but uses data on timing obtained during escapement monitoring. In-

season evaluation of adult stocks is possible using jack sockeye scales obtained in the previous-year spawning-ground enumeration program. A post-season evaluation is performed in order to include more precise timing data and to use the spawning ground adult scales and age composition in the racial analysis.

SPAWNER-RECRUIT ANALYSIS

Sockeye stocks are enumerated and analysed individually since production patterns differ widely. We find that each life history stage contributes to the typical large variance around the spawner-recruit curve. In order to minimize that variance component associated with spawning stock, the Commission uses the "effective female" population for studies of Fraser sockeye. The "effective female" population is the product of weighted spawning success and female population size. Variance in the spawner-recruit relationship associated with both sex ratio and spawning success is, thus, eliminated.

Brood year production by age group and stock is estimated in the racial analysis. Catch estimates by stock have variability similar to the escapement estimates. Confidence limits have not been computed; however, the larger stocks would have lower percentage variability due to their dominance in the fishery and hence, lower probability of significant error. For these stocks the spawning-ground enumeration produces confidence intervals in the order of 10% to 20% of the point estimate. Maintenance of tight confidence limits on the production estimates is therefore important to the accuracy and utility of the spawner-recruit relationship.

Many sockeye stocks in the upper Fraser watershed exhibit cyclic production patterns with dominant returns every fourth year (Ward and Larkin, 1964). The spawner-recruit analysis is best applied to individual cycles. For example, in the Stellako River the 1982 and 1983 lines are co-dominant and have similar reproduction relationships. The spawner-recruit analysis indicates an optimum escapement of 168,000 spawners with a 95% confidence interval of 127,000 to 239,000 escapement (i.e. -24.3% to +42.2%). The sensitivity of this analysis to errors in escapement estimates has been examined to determine ranges on optimum effective female escapement. This examination revealed that when upper and lower confidence interval estimates for the annual female escapements are used, the optimum escapement varies by approximately $\pm$10% (+8.9%, -12.6%). Thus, error in the spawning ground escapement estimates would appear to contribute little to the overall spawner-recruit variance and can be considered quite adequate for management decisions.

FORECASTING

The fishery manager may use the spawner-recruit relationship to obtain an initial forecast of recruitment. However, the Commission prefers to use jack (3-year-old) sockeye data to forecast following year adult production where possible. Spawner-recruit estimates are mainly used when jack data are scarce or lacking.

Jack sockeye returns, size and scale-growth data are used in regression analysis for forecasting the return of 4-year-old adults. Production of jacks (i.e. catch plus escapement) is the basic forecasting variable; however, first-year marine growth measurements from spawning ground scales and length of jacks have proven important in the predictive equations.

Spawning-ground programs provide the jack sockeye data needed for the forecasting process. Enumeration of the jack population is an important feature of the Commission program. Escapement of jacks may approach one-half of the total return in some years. Tagging estimates of the jack populations have good confidence limits where large jack populations occur (e.g. Adams River dominant cycle: $\bar{X} = 62{,}000$). Tagging of 2% of the population and recovery of 10% are common levels of enumeration effort which gives a 95% confidence interval of approximately 40% of the point estimate. Small returns for stocks which normally produce few jacks would give less precise estimates of the escapement. In these cases, the recovery rate for adult males is applied to the recoveries of jacks.

Scale collection and length measurements of jacks on the spawning grounds are also priority tasks. In the lab, scale growth is measured and circuli are counted. Freshwater growth is density dependent in most stocks. Thus, the number of circuli indicate juvenile population abundance. The early marine growth obtained from scales and length of jacks can supply maturation schedule information used in multiple regressions with jack abundance to predict 4_2 returns.

SUMMARY

Escapement estimates at the point of passage from commercial fishing areas and on the spawning grounds provide the fishery manager with those data required for accurate forecasting, in establishment of preseason escapement goals and in reaching those goals by regulation of the fishery. Commission programs are oriented to provide a continuous flow of escapement data for immediate introduction into the in-season management of the commercial fishery.

Spawning ground enumeration programs are dictated by the data requirements and by population size and logistics. Mark-recapture and visual estimates provide the bulk of escapement data. Extensive biological sampling is conducted to provide the manager with in-depth information.

Spawner-recruit relationships have been analysed for sensitivity to errors in the escapement estimation procedure. The results indicate that only a small portion of the observed variability in spawner-recruit curves can be explained by enumeration errors. These curves provide estimates of optimum escapement and initial forecasts for individual year returns.

Forecasting is highly dependent upon the accuracy of jack sockeye escapement estimates particularly in years and areas of low production. Enumeration programs provide the data on jack abundance, scales and length for the forecast of subsequent year returns. Jack scales also provide circuli count distributions for in-season racial analysis of adult returns.

Integrated data collection programs are designed to provide the fishery manager with the necessary data to effectively forecast the returns and attain the escapement goals by in-season regulation of the fishery.

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PUGET SOUND CHUM SALMON ESCAPEMENT ESTIMATES USING SPAWNER CURVE METHODOLOGY

by

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Introduction

The Washington Department of Fisheries (WDF) first developed a program to annually evaluate the escapement of naturally produced Puget Sound salmon stocks in 1951 (Egan 1982). Standardized stream areas (indexes) were surveyed each year and peak fish-per-mile counts (live plus dead) were used as relative measures of spawner abundance. In subsequent years, a wide variety of approaches have been used in an attempt to increase the accuracy of escapement estimates. Some methodologies that have been tried or are currently used in Puget Sound include: foot and boat counts, aerial counts, weir/trap counts, fishway counts, electronic counts, carcass tagging, and tag and recovery estimates.

One of the most valuable methodologies for estimating escapement is the use of spawner (or redd) curves constructed from serial survey counts, coupled with various factors which convert the area under the curve (AUC) into estimates of spawner abundance. One of the first uses of this technique for Puget Sound salmon stocks was the comparison of the 1969 Cedar River sockeye weir counts with an AUC estimate of escapement based on boat survey counts (Ames-WDF, unpubl). In 1977, Russ Orrell (WDF) developed a methodology for estimating escapement for Skagit River summer/fall chinook using the AUC technique with aerial redd counts, an approach that was subsequently applied to the other major Puget Sound chinook streams (Ames and Phinney 1977). All escapement estimates for South Sound and Hood Canal chum stocks were recalculated in 1978 using the spawner curve methodology (Ames 1978), and north Puget Sound chum estimates were redone in 1983 using the same approach (Hendricks-WDF unpubl.). A long-term tower counting program for Cedar River sockeye was dropped in 1982 in favor of the spawner curve method, because over a 13-year span, spawner curves had produced comparable escapement estimates with much lower manpower requirements. Puget Sound coho escapements were recalculated in 1983 using the AUC method to produce relative estimates of spawner abundance from index area counts (Flint 1983).

The spawner curve methodology has become a major technique for the estimation of Puget Sound salmon escapement, and a number of limited evaluations have shown it to be of acceptable accuracy when survey conditions are good. Probably the best situation for using this procedure is with chum salmon in small spawning streams (under 100 cfs). Puget Sound chum spawners typically utilize the lower reaches of these streams, and it is generally possible to survey the entire spawning area. In addition, chum tend to move onto spawning riffles shortly after entering the spawning area and are highly visible to surveyors. Because of these factors, this paper will utilize chum salmon data collected

from Perry Creek in southern Puget Sound as an example of how spawner curves are used to estimate escapement. The entire WDF procedure will be described, including counting, data assembly and processing, the construction of curves, and the conversion of AUC to spawner estimates. The example chosen is intentionally an ideal situation, so a discussion of the problems associated with this methodology follows. The final section of this paper outlines two WDF escapement data systems that are currently under development.

Spawner Curve Methodology

Perry Creek is typical of the small salmon production streams that flow directly into the marine waters of southern Puget Sound and Hood Canal. The stream is 4.5 miles in length and is blocked to anadromous fish use by an impassable waterfall at River Mile (RM) 1.5. During the chum salmon spawning season (November and December), the accessible portions of Perry Creek have an average flow of 25-30 cfs, and an average stream width of approximately 25 feet. Annual chum salmon escapements (1968-82) have averaged 4,750 spawners, with a range of 1,650 to 11,850 fish. This stream was selected as an example for this report because of its sizable chum spawning population and because it has consistently good survey conditions.

Spawner counts

Over the past five years (1978-82), an annual average of 3,235 miles of spawner surveys have been conducted on Puget Sound streams. Of this total, 2,585 miles are done by WDF staff and 650 miles are the result of tribal and other agency surveys. Of the total average survey mileage, 63% is done on foot, 22% by helicopter or fixed-wing aircraft, and 15% by boat (Egan 1983).

Foot surveys are conducted on small streams, generally under 100 cfs during the spawning period, and are the primary counting method for chum salmon. Approximately 1,075 miles of chum surveys are conducted each year. The WDF surveys are done primarily by seasonal employees hired specifically for spawning ground work. Normally, about 50% of these temporary workers have prior experience on WDF survey crews. The surveyors are supervised by fulltime WDF biologists or scientific technicians, at a ratio of 3 or 4 temporary workers per each field supervisor. The training period for first-time stream surveyors involves 3-5 days in the field with the supervisor and covers species identification, counting procedures, and recording of data.

Teams of two surveyors are assigned a series of streams to be counted during 3- to 5-day periods. A team will typically survey between five and 10 streams per day, with survey lengths ranging between 0.5 mile to 2.5 miles per stream. The number of streams covered each day is dependent on lengths of surveys and the travel distances between streams. An attempt is made to count each individual stream every 7 to 10 days, survey conditions permitting.

The survey areas are divided into two sections, based on ease of access or the amount of time required to make the count, and each team member walks a separate area. Polarized glasses are worn by the surveyors to increase visibility, and all live and dead fish are counted on mechanical tally counters. Wherever possible, streams are walked downstream because spawners when startled will tend to move upstream past the surveyor and more accurate counts result. In most situations, chum salmon spawn in discrete and somewhat limited stream areas, making it possible to survey the entire spawning area. At the completion of a survey, the counts, area surveyed, and estimates of visibility are recorded in field books. These books are collected at the end of the season and are kept in WDF files.

The 1978 chum escapement to Perry Creek has been chosen to illustrate the methodologies discussed in this paper. Nine chum surveys were conducted on Perry Creek between November 9, 1978, and December 28, 1978 (Figure 1). Survey frequency ranged from 4-10 days, with a 7-day average. Two surveys were made by Squaxin tribal personnel, one on the same day as a WDF survey (November 21, 1978). The lower section of the survey area is under tidal influence and the first two surveys were slightly shortened because of high tides. The counts began with 19 live chum November 9, peaked with 2,452 live and 240 dead chum on December 14, and had declined to 468 live and 1,522 dead on the final survey on December 28.

Data assembly

Once each week, survey teams are required to record their counts on survey cards (Figure 2). These cards are the primary WDF escapement data storage system, with the field books as backup. The survey cards are formatted to allow direct keypunching for computer storage. A separate card is filled out for each species observed on an individual survey, and data recorded include the survey date, survey length, live and dead counts, and estimates of visibility.

In order to efficiently handle survey data with computer applications, it is necessary to have some systematic method of identifying both the streams and the areas surveyed. In the early 1970s, WDF developed a catalog of Puget Sound streams (Williams et al. 1975) and a Puget Sound river mile index (Ames and Bucknell 1981). These two documents present a standardized stream numbering system, a set of individual stream maps with a scale of one inch=one mile, and standardized stream mile locations. The catalog and river mile index systems have proved invaluable in the assembly and storage of spawning ground data. The appropriate stream number is used to identify streams on the survey cards, and the upper and lower end of the area surveyed is indicated to the nearest one-tenth mile. Egan (1983) presents a detailed description of the WDF survey card and the data entries in each category.

The completed survey cards are submitted to the field supervisor who proofs the cards for obvious errors. Survey cards from all sources, including other agencies and tribal staffs, are then directed to a single individual in WDF who is responsible for the escapement data system. The cards are proofed for a second time and then go to the WDF Data Processing Section for keypunching. Periodically throughout the season, the field supervisors receive printouts of

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SALMON SPAWNING GROUND DATA RETRIEVAL

WRIA NO.	STRM NO.	DATE YR MO DY	RIVER MILE LOW END	RIVER MILE UPPER END	LNGTH	SPEC NAME	LIVE COUNT	DEAD COUNT	TOTAL COUNT	FISH PER MILE	SPECIES CODE	PER CENT SEEN	REDD COUNT	TYPE COUNT	TYPE SURVEY	OTHER SPECIES SEEN	COMMENTS 1 2 3	ACODE
SHELTON BASIN																		
PERRY CREEK																		
14	0001	78/11/09	0.1	1.5	1.4	CHUM	19	0	19	13.5	2	80		INDX	FOOT		21	
14	0001	78/11/13	0.2	1.5	1.3	CHUM	1	1	2	1.5	2	95		INDX	FOOT	4 0 0 0	20	
14	0001	78/11/21	0.0	1.5	1.5	CHUM	93	3	98	65.3	2	70		INDX	FOOT	4 0 0 0	26 60	
14	0001	78/11/21	0.0	1.5	1.5	CHUM	113	3	116	77.3	2	90		INDX	FOOT		26 41 40	26
14	0001	78/11/27	0.0	1.5	1.5	CHUM	360	1	361	240.6	2	80		INDX	FOOT		23	26
14	0001	78/12/04	0.0	1.5	1.5	CHUM	1191	20	1211	807.3	2	60		INDX	FOOT	4 0 0 0	27	
14	0001	78/12/14	0.0	1.5	1.5	CHUM	2452	240	2692	1794.6	2	65		INDX	FOOT		60	
14	0001	78/12/20	0.0	1.5	1.5	CHUM	1718	511	2229	1486.0	2	80		INDX	FOOT			
14	0001	78/12/28	0.0	1.5	1.5	CHUM	468	1522	1990	1326.6	2	80		INDX	FOOT			

Figure 1. Example of Puget Sound spawning ground data retrieval system showing the 1978 Perry Creek chum salmon counts.

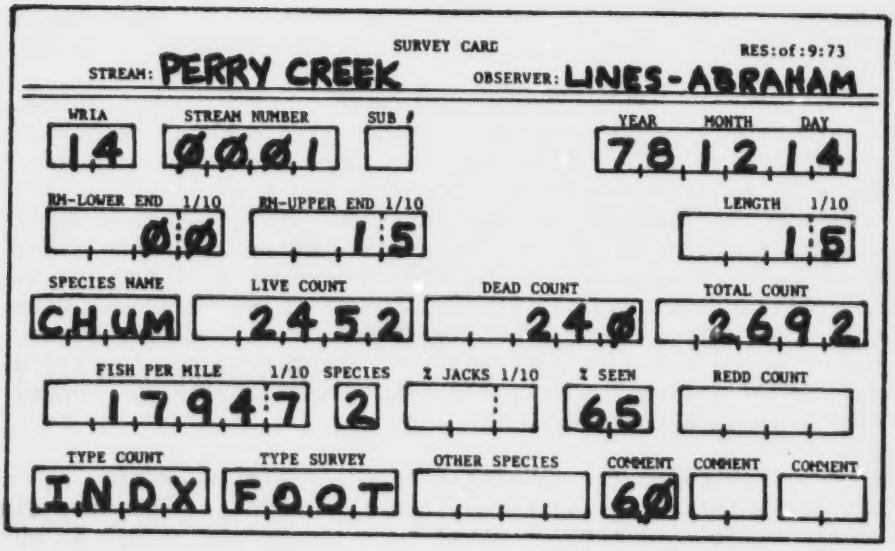

Figure 2. Example of WDF spawning ground survey card showing the 12/14/1978 chum salmon count in Perry Creek.

all data that have been processed. These printouts are used to check survey scheduling and to verify that all surveys have been properly documented. At the conclusion of the survey season, a total season printout is produced, and is again proofed by the field supervisor to identify missing surveys, incorrect data entries, and keypunch errors. This results in additional printouts by species, which are used in the escapement estimation procedure.

Figure 1 is an example of the printout showing the nine chum surveys conducted on Perry Creek during the 1978 season. The sample survey card (Figure 2) displays the data collected on the peak survey on December 14, 1978.

Escapement estimation

The escapement methodology described here is used only for Puget Sound chum salmon. The methods used for other species in some cases vary considerably from the chum salmon procedures. This is most often the result of differences in the quality of spawning ground data that can be collected. For example, while the spawner curve method produces good results with Puget Sound chum stocks, it is seldom used for pink salmon because reliable live counts cannot be obtained on large river systems. As was mentioned earlier, variations of the methodology are used for Puget Sound chinook, coho, and sockeye escapement estimates.

When the spawning ground surveys have been completed for a specific chum stock, e.g. normal-timed South Sound chum, the actual counts for each survey area are plotted on graph paper by the field supervisor. A series of values representing the counts adjusted for the estimated percent visibility are also included on the graph. Figure 3 presents the 1978 Perry Creek data, with O's depicting the actual counts and X's representing the adjusted counts. As a general rule, incomplete surveys and those with less than 50% visibility are not used. However, if good counts are not available for a critical period like the peak of spawning, normally unacceptable counts will be considered when fitting a line to the spawner data. During the process of plotting the spawner counts, the field supervisor final proofs the data by identifying missing surveys and suspect counts.

A line is fit by eye to the spawner data on each graph. In an attempt to achieve some degree of consistency, all curves are drawn by the same individual for each region. The approach used for chum data is to fit the line between the actual and observed values (Figure 3). For stream areas where good survey conditions prevail, i.e., limited in-stream cover and generally clear water, the line will be placed close to the actual spawner values. Perry Creek is an example of this situation. The line is fit closer to the adjusted values for streams where water color and in-stream cover limit viewing conditions. While this approach does introduce a degree of subjectivity into the derivation of escapement estimates, the author believes that the resulting values are closer to the actual numbers of spawners. Another common situation where fitting the line between the actual and adjusted values results in a more accurate estimate, is when a count is made during a period of poor visibility. As an example, assume that an additional survey had been conducted on Perry Creek on December

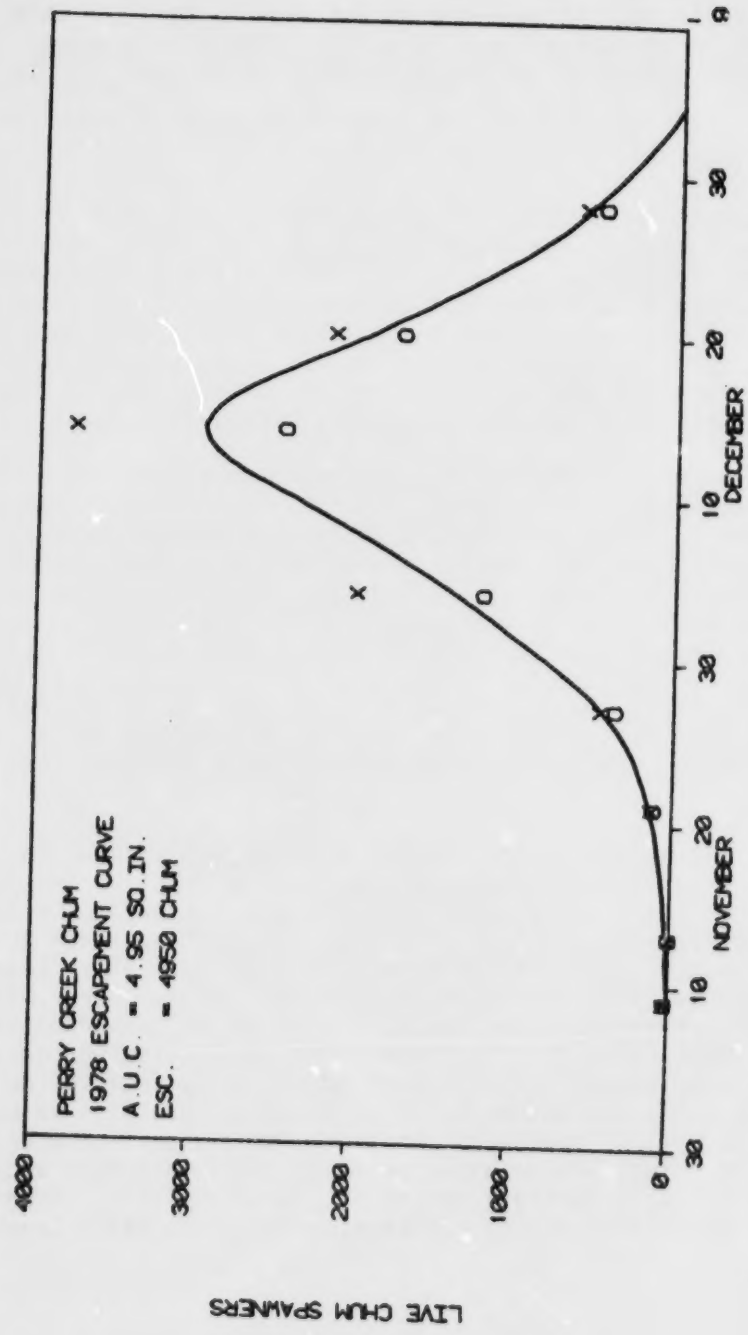

Figure 3. Perry Creek chum salmon spawner curve, 1978.

7, 1978, with a count of 1,000 live chum and an estimate of 50% visibility. If this count were added to Figure 3 and the line fit to the actual values, a bi-modal ecapement pattern would result and the estimate of numbers of spawners would be significantly reduced. With the WDF approach, the line would be fit between the actual value (1,000 spawners) and the adjusted value (2,000 spawners), and the curve presented in Figure 3 would be unchanged.

The 1978 Perry Creek chum data were selected as an example because of an excellent series of counts resulting in a normally distributed curve. Escapement curves with a normal-type distribution are common among Puget Sound chum stocks; however, a variety of other shapes of curves do occur. Two factors that have been observed to influence the shape of chum escapement curves are extreme environmental conditions and fishery removals. Figure 4 presents Perry Creek escapement curves for three additional years. The shape of the 1976 curve was a direct result of stream flow patterns during a period of extreme drought. Regional stream gauge records (South Fork Skokomish River) show low November stream flows until a freshet beginning on November 5, 1976, which corresponds to the first significant movement of chum into Perry Creek. Stream flows fell from November 17 to December 8, after which higher flows prevailed. This December flow increase generated the movement of the main group of chum spawners into the stream. Another environmental factor that alters the shape of spawner curves is an extended period of extreme low temperatures. The migration of chum salmon into small streams can be stopped by low water temperatures, resulting in flat-topped or bi-modal curves.

The 1977 curve in Figure 4 takes a flat-topped form. There were no observed environmental conditions that would account for the lack of a distinct peak, and fishery removals of a portion of the November 30 to December 20 spawners is a possible explanation. The curve representing the 1982 escapement suggests that the majority of the chum that would have spawned between November 20 and December 10 were caught prior to entering freshwater.

Another observation based on the escapement curves presented in Figures 3 and 4 is that the peak live count is not a reliable indicator of total spawner abundance. The total escapement, peak live counts, and the peak count as a percentage of total escapement for 1976, 1977, 1978, and 1982 are shown in Table 1. Peak counts represented between 27.3% and 72.7% of total escapements, showing that with salmon stocks exhibiting variable escapement curves, peak counts are not valid measures of escapement.

When curves have been developed from the spawning ground data, area under the curve is measured with a compensating polar planimeter. In the Perry Creek example (Figure 3), AUC equals 4.95 square inches. AUC is then multiplied by the number of fish days in one square inch to arrive at the total number of fish days during the spawning period. For the 1978 Perry Creek escapement, 4.95 $inches^2$ at 10,000 fish days/$inch^2$ equals 49,500 total spawner days. This value can be used as an index of relative abundance if it is impossible to count a high proportion of the total spawner population. Puget Sound coho escapement is estimated in this manner, with total spawner days in a number of stream indexes related to base year estimates of total river system escapement (Flint 1983).

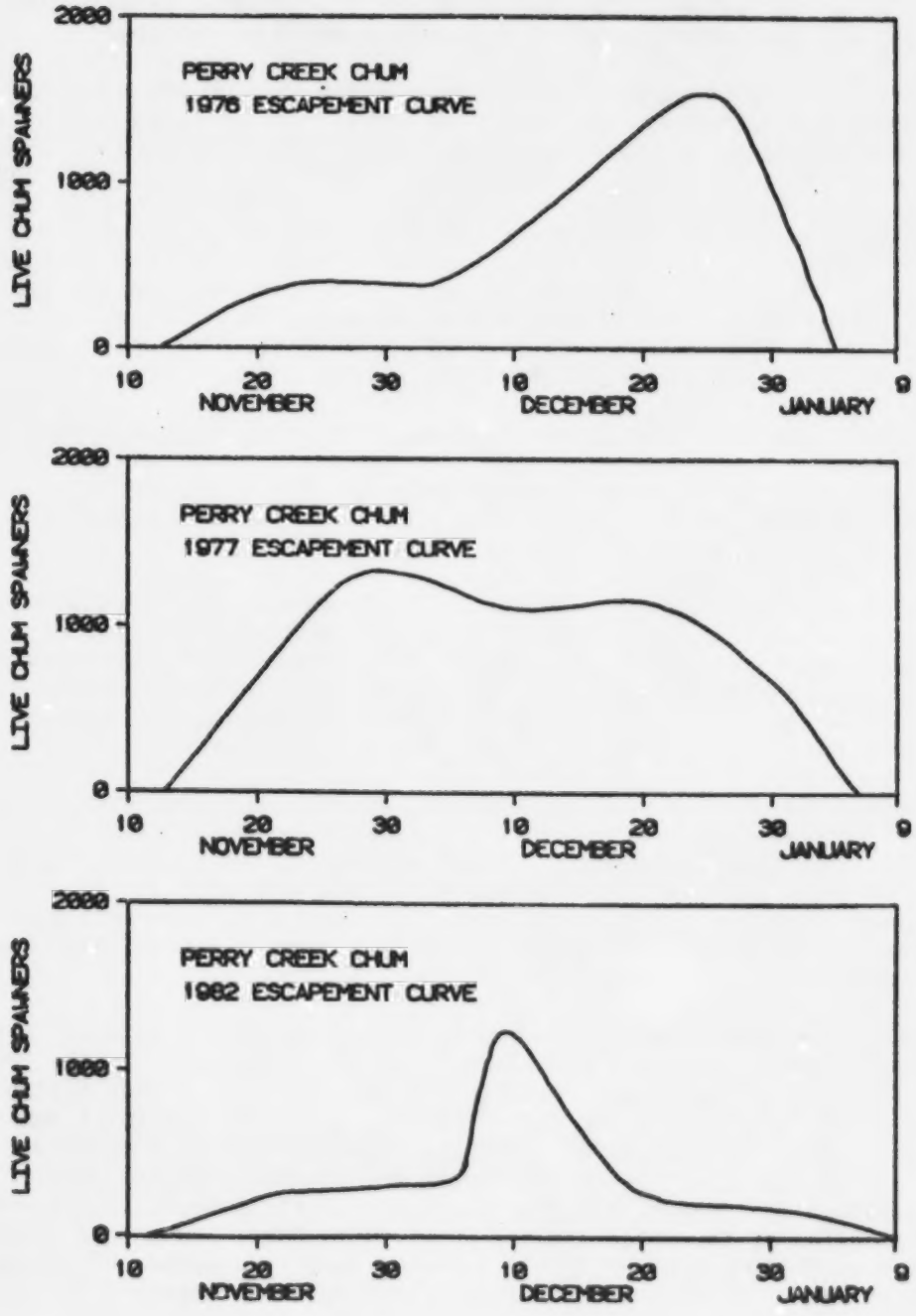

Figure 4. Comparison of shapes of spawner curves from Perry Creek, 1976, 1977, and 1982.

Table 1. Comparison of peak abundance to total escapements, Perry Creek chum, 1976-1978 and 1982.

Return year	Total escapement	Peak live abundance	Peak abundance percentage
1976	3,590	1,400	39.0
1977	4,760	1,300	27.3
1978	4,950	2,900	58.6
1982	1,650	1,200	72.7

Table 2. Chum salmon survey life values for four streams in Puget Sound.

Stream	Return year	Stock timing	Survey life (days)	Method[a/]	Stream type
Minter Creek	1952	Normal	10.5	W/T/R	Tributary to saltwater
Perkins Creek	1974	Normal	9.5	W/T/R	Tributary to small stream
Johns Creek	1977	Early	10.1	W/T/R	Tributary to saltwater
Yelm Creek	1976-81	Late	9.7	AUC/N	Tributary to large stream

a/ W/T/R = weir, tagged fish, with periodic carcass recovery.
AUC/N = area under spawner curve (fish days) divided by known population size.

Estimates of total spawner days can be converted into actual escapement if the average number of days a spawner spends in the survey area (survey life) is known. Survey life differs from stream life in that it is the number of days that the average spawner can be counted as a live fish in a survey area and is not always equal to total freshwater life. In large river systems, for example, chum salmon stream life may include several weeks spent in the mainstem prior to moving into smaller tributaries where they can be counted. For Puget Sound chum, an average survey life of 10 days is used to estimate actual escapement from spawner curves. In the Perry Creek example, the 49,500 spawner days is divided by 10 days per spawner, resulting in a total escapement of 4,950 chum in 1978.

The 10-day chum survey life value is derived from the findings of four separate studies (Table 2). The 1952 Minter Creek study (Salo and Noble 1952) involved tagged chum released above a weir and periodic recovery of tagged carcasses. The average survey life of Minter Creek chum was estimated at 7 to 12 days with a median value of 9.5 days. Both the Perkins and Johns Creek studies (WDF unpubl.) used tagged fish above a weir and daily carcass recovery, and survey life was estimated to be 8.5 and 9.1 days, respectively. For each of the three studies above, one additional day has been included in the survey life values in Table 2 because the spawners were required to spend some time approaching and entering a trap at a weir. The fourth study was conducted by the Nisqually Tribe (Svoboda and Harrington-Tweit 1983) on Yelm Creek and estimated the average survey life for six seasons to be 9.7 days. This study used AUC estimates of total spawner days divided by total spawners estimated with carcass mark and recovery techniques. Because the spawners had free access to the survey area, i.e. no weir was used, the 9.7 day value was used without adding an extra day. The four studies presented in Table 2 span 30 years, include early, normal, and late chum stocks, and were conducted on a variety of stream types. The average survey life found by these studies was 9.95 days, with a standard deviation of 0.44 days.

When total chum spawner values have been calculated for individual streams, each is checked against the peak live and dead count for the season. Occasionally, a total escapement estimate will be too low when compared to the peak count. In such cases, the survey data are re-examined, and invariably the peak of the spawner curve was drawn too low because of extended gaps in survey coverage during critical time periods. Such curves are redrawn using the peak dead count as an indicator of probable peak live abundance, and a new escapement estimate is generated.

At this point, two separate methods are used to finalize total escapement estimates, based on the size of the streams. For the major river systems, those in northern Puget Sound and the Nisqually River, all spawning areas cannot be surveyed. The escapement estimates for those areas that can be surveyed are related to escapements that occurred in the same areas during base years when total system escapement estimates were made with tag and recovery studies and total escapement for the current year is calculated. For southern Puget Sound and Hood Canal stocks, over 80% of the total escapement is directly accounted for with spawner curve estimates. Escapements to those areas not surveyed on a regular basis are estimated using the observed variations from mean escapement for the current year on nearby streams with spawner curve estimates.

Discussion of Problems

To date, the spawner curve escapement methodology has proven to be the best way that WDF found to convert spawning ground survey data into acceptable escapement estimates. The major limitation of this methodology is that it can only be used successfully where reasonably good visual spawner counts can be made. In addition, there are several problems inherent in the methodology that potentially can affect the relative accuracy of resulting escapement estimates.

Insufficient data

The development of an accurate spawner curve requires a series of spawner counts made under good viewing conditions. Ideally, survey frequency should be no longer than the average survey life of the species being counted: 10 days for Puget Sound chum. An even shorter survey frequency is desirable during the period of peak spawner abundance, so that the magnitude of the peak can be accurately represented on the spawner curve. Unfortunately, manpower limitations and bad weather conditions often cause significant gaps in survey coverage. A number of methods have been used by WDF to estimate chum escapements when survey data are incomplete.

As was mentioned earlier, dead counts can sometimes be used to estimate previous live spawner abundance. If the gap in survey coverage was caused by flooding, however, subsequent carcass counts will be low and of little use. If sufficient surveys were conducted to give a general idea of the shape of the curve and it suggests a normal distribution, a normalized-curve will likely approximate the missing data.

An extended gap in counts will probably necessitate the consideration of information from other sources. One approach is to examine spawner curves from adjacent streams. If the chum runs are of the same timing and have been subjected to similar environmental and fishery influences, spawner curves from neighboring streams may help to estimate missing data. Often, a stream's spawner curves from past years will show consistent patterns that may be of some assistance in estimating missing data, particularly the timing of beginning, peak, and end of the run. Consistently shaped curves are usually characteristic of larger streams where environmental influences on spawner entry patterns are minimal. Based on the variation shown in Figures 3 and 4, historical data would be of little use for Perry Creek.

When available spawning ground counts are felt to be totally unreliable, or are completely missing, escapements are estimated using the proportionate increases or decreases in escapement to other streams in the same management area. This approach is the last resort, because it uses no specific information, other than past mean escapement, from the stream in question. It is obvious that as the quality of the survey data declines, the subjectivity of the estimate increases and becomes more dependent on the experience of the individual developing the estimates.

Estimates of visibility

There is probably no more controversial aspect of the spawner curve methodology than the estimation of visibility. There are some small streams and side channel areas where virtually 100% of the fish present can be counted, but such areas are extremely rare. There are few, if any, observers who would count spawners in a typical salmon spawning stream and claim to have seen every fish. When attempting to develop estimates of total escapement, the problem is how counts should be adjusted to account for visibility problems. There is no consensus opinion within WDF, and each individual responsible for developing escapement estimates approaches the problem differently. The chum salmon methodology, as discussed above, uses estimates of percent visibility made by the individuals who conducted the counts. These estimates of visibility are used only as upper limit guidelines for fitting curves to escapement data, and are not used as automatic adjustment factors. This is an effective way of correcting counts made with abnormal viewing conditions, but it will likely be proved to be a conservative approach for adjusting normal counts to account for all spawners present.

Survey life

Based on the data in Table 2, the survey life of Puget Sound chum spawners is remarkably uniform. There are several factors, however, that potentially can alter survey life and affect the accuracy of escapement estimates based on spawner curves. Data collected during the 1977 Johns Creek chum study showed sexual differences in spawner survey life. Male chum spawners lived an average of 9.8 days, while female spawners survived an average of 10.8 days. If sex ratios were altered, by selective fishery removals, for example, the 10-day survey life factor would not be correct. Run timing also affected average survey life in the Johns Creek study. Estimates of survey life for the first half of the run averaged 10.7 days, opposed to a value of 9.7 days for the last half of the run. In a situation like the 1982 Perry Creek escapement (Figure 4), major fishery removals of the early spawners could cause shortened survey life. It is also possible that runs delayed by extreme environmental factors could experience a compression of spawner survey life. Ideally, the spawner curve methodology would use annually adjusted survey life factors, but this refinement will have to await the accumulation of more data on survey life.

Spawners below weirs

In recent years, the increase in chum brood stock collection on Puget Sound streams has created a difficult situation for estimating escapement. Temporary weirs are used to block migration and trap brood stock. The chum that spawn below these weirs are mixed with large numbers of fish in transit to upstream areas. No satisfactory method has been developed to estimate the downstream spawning population. On very small streams, dead counts are used to obtain a rough estimate of spawners. An approach that has been used on larger streams is to develop a spawner curve for the downstream area. This curve includes both spawners and fish in transit. A reduced survey life value is calculated based

on 10 days for the spawning fish and the estimated travel time for the upstream fish. The total population below the weir is estimated using the spawner curve and the reduced survey life, and the number of fish counted at the weir is subtracted from the total to arrive at an estimate of the downstream spawning population.

Future Escapement Programs

Two computer programs are currently under development by WDF which will increase the efficiency of escapement estimation procedures. Both programs will be available for the 1984 spawning season.

Interactive spawning ground data system

Over 35,000 individual spawning ground surveys have been conducted on Puget Sound streams and are documented in WDF computer files. In recent years, an increasing number of surveys are being added to the WDF system by various other governmental agencies and by the technical staffs of 13 different Indian tribes. To facilitate the access to, and analysis of spawning ground data, an interactive computer program is under development by WDF. All historical Puget Sound spawning ground data will be on file at the University of Washington Computer Center, and anyone with a remote terminal will be able to access, assemble, and copy any of the data. An attempt will also be made to get in-season data (unproofed) into the system within 7 days of the survey date. If this can be accomplished, survey scheduling and data checking will be greatly simplified.

Interactive spawner curve program

Two problems with the current spawner curve methodology that have become apparent are that hand-drawn spawner curves cannot be exactly reproduced, and that the potential exists for measurement errors when using a planimeter to derive AUC. WDF is currently developing a computer program that will allow the development of spawner curves on a high-resolution graphics terminal. This interactive program will directly access the spawning ground data file, and will allow the operator to: edit data; plot live, dead or redd counts; adjust counts for visibility; automatically measure AUC; select any survey life value; compute total escapement; and produce a hard copy of the results. It is planned to eventually recalculate all past chum escapement estimates using this system.

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A COMPARISON OF STREAM INDEXING METHODS TO ESTIMATE COHO ESCAPEMENTS IN HARRIS CREEK, 1980 - 1983

by

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Introduction

A stream index system to estimate coho escapements in Puget Sound was developed in 1951 (Egan, 1982). Coho index areas are sections of, or entire, spawning streams that are assumed to represent spawning escapements in a region or river basin. These "index" areas are surveyed on foot during the spawning season, and visual counts of both live and dead coho are made. Until recently, peak total (live plus dead) counts from these index areas were used to obtain a relative measure of spawning escapement between years (Zilliges, 1974 and 1977). This was done by first establishing a base year (1965) for which total escapements were estimated based on physical stream survey data, fish counts, and individual expertise available at the time. 1965 was selected as the base year because escapements were believed to be about "average". Then peak fish-per-mile counts in each subsequent year were compared with those in the base year to estimate escapements.

Flint (1983) updated Puget Sound coho escapement methodology because of: (1) recent adult population studies in some basins; (2) an expanded spawning ground index system; (3) accurate total counts at upstream weirs and traps; and (4) the assumption that escapement curve methodology more accurately reflects relative spawning escapements among years. The new methodology established more recent base year escapement estimates. Live counts are then plotted by date for each index area. A computer program measures the area under the curve expressed as "spawner days" for each index area. The sum of escapement curve areas (spawner days) in each region is compared with the same index values calculated for the base year. Total escapement is then computed using the following formula:

$$\frac{\text{total spawner days in year } i}{\text{total spawner days in base year}} \times \text{base year escapement estimate} = \text{estimated escapement in year } i$$

Because it is important to evaluate this escapement methodology, the Washington Department of Fisheries (WDF) has several ongoing studies. One such study for which preliminary data are available is located on Harris Creek, a tributary of the Snoqualmie River in northern Puget Sound. An adult weir was operated at Harris Creek from 1980 to 1983. WDF had established coho index areas on Harris Creek and its tributaries which provided an opportunity to compare several index estimators with known escapements.

Methods

Description of stream

Harris Creek drains into the Snoqualmie River approximately 40 miles above saltwater in northern Puget Sound. The stream has a mainstem length of approximately 6.4 miles, all of which is accessible to anadromous fish. Several small tributaries account for an additional 3.2 miles of accessible spawning habitat. Mean winter flows range from 15 to 50 cfs with some peak flows in excess of 500 cfs. Average summer flows are approximately 3-6 cfs.

Fish usage

Coho salmon, steelhead trout, and cutthroat trout are the only anadromous salmonids known to currently utilize the watershed. The coho run usually commences in mid-November and peaks in December; however, in some years, substantial spawning has occurred throughout January and into February. Figure 1 shows the variations in run timing which occurred in 1976 and 1977.

Study area

The adult weir was located at River Mile 1.5 and only one significant tributary (Stillwater Creek) enters the stream below this point. Coho spawning is minimal below the weir site; however, some coho utilize Stillwater Creek. The index area on Harris Creek is located between River miles 4.5 and 5.3. This accounts for approximately 16% of the mainstem area above the weir. This index area is by no means ideal compared with other coho index areas in Puget Sound. Much of this section is deep and dark, and visibility in pools is limited. Other parts of this index (where most of the spawning occurs) are shallower with better visibility. For the entire section, surveyors typically estimate visibility at 40% to 70%. In addition, indexes totalling 1.8 miles on four small tributaries account for approximately 80% of the accessible tributary habitat above the weir. These streams are small, and most of the fish (80% to 95%) are typically counted. The combined indexes above the weir account for roughly 37% of the accessible habitat.

Index surveys

Foot surveys were conducted weekly in each index area as water conditions allowed. Live and dead counts were made with the aid of polarized glasses. A number of different permanent and temporary personnel conducted index surveys during the four years of the study.

Weir counts

Table 1 presents the total estimated adult coho returns above the weir for the years 1980-1983. Adults were marked with opercle punches at the weir and carcasses were sampled upstream so that a total escapement estimate could be obtained even if the weir washed out.

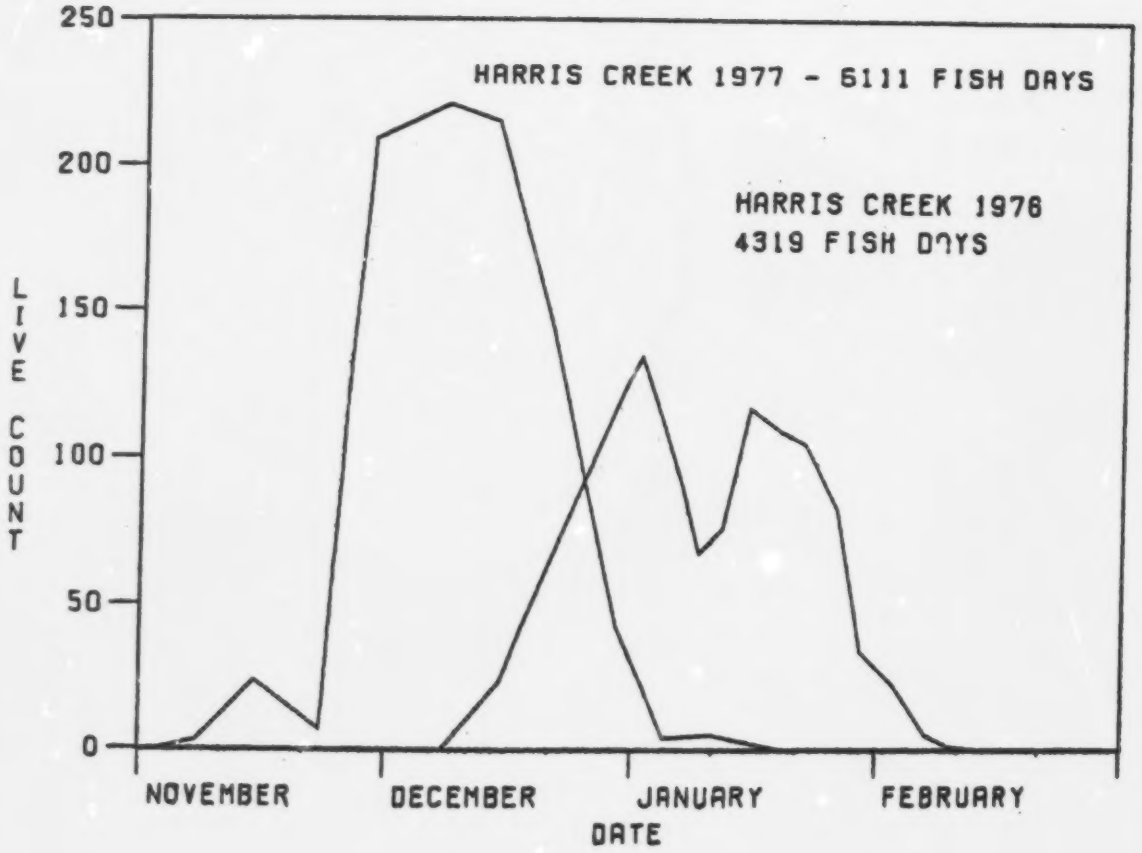

Figure 1. Harris Creek coho live counts by date for 1976 and 1977.

1980. High flows washed out the weir near peak migration. An estimated 41% of the run was trapped. Carcasses were sampled throughout the entire season above the weir. A simple Petersen estimate was used to estimate the adult return at 2,360 coho with 95% confidence limits of 2,120 to 2,651.

1981. Some escapement apparently occurred prior to placement of the weir and carcasses were sampled above the weir the entire season. The Petersen estimate was 961 coho with 95% confidence limits of 918 to 1,050. An estimated 91% of the run was trapped.

1982. The weir washed out late in the season. The area above the weir was sampled for mark ratios after the was out only. A stratified population estimate was less than the actual number of fish handled at the weir. Therefore, a simple Petersen estimate was used which estimated 2,197 fish with 95% confidence limits of 2,140 to 2,257. An estimated 9[illegible] of the run was trapped in 1982.

1983. The weir did not wash out during the season and a total count was obtained.

Results and Discussion

Peak live and peak total (live plus dead) index counts are presented in Table 1. Peak live counts in the Harris Creek index ranged from 42 in 1981 to 447 in 1983. These peak counts represented 4.4% to 8.0% of the total escapement (Table 2). Combined peak live counts in the tributary indexes ranged from 50 in 1981 to 330 in 1983. The sum of peak live counts for all indexes represented 9.2% to 14% of the total return.

Peak total (live plus dead) counts ranged from 42 to 625 in the Harris Creek index which accounted for 4.4% to 11.2%, respectively, of the spawning escapement. Peak total counts for the combined tributary indexes ranged from 52 in 1981 to 345 in 1983. The sum of peak live plus dead counts for all index areas represented 9.8% to 17.4% of the total escapement above the weir.

Escapement curves were constructed using live counts by date for each index area. The area under the curve was then calculated to arrive at a "spawner day" value for each index. A "spawner day" is simply one live coho in the index area for one day. Escapement curve areas expressed as spawner days for the Harris Creek index and the combined tributary indexes are presented in Table 1.

Estimated spawner days for the Harris Creek index ranged from 1,018 to 15,062. For the combined tributaries, the escapement curve area ranged from 1,023 spawner days in 1981 to 7,367 spawner days in 1983. By applying a 10-day average redd (index) life (observed for other species) to the total spawner days for all index areas and dividing by the estimated adult return, a rough idea of the percentage of the population represented by these indexes was obtained. Using this procedure, observed fish in all index areas represented from 21% to 40% of the actual escapement (Table 1).

Table 1. Estimated adult coho return; index spawner days, peak live, and peak live and dead counts in Harris Creek, 1980-1983.

Return Year	Type Estimate	Est. Total Adult Return	Est. % of Run Trapped	95% CI Lower	95% CI Upper	Harris Spawner Days	Harris Tribs. Spawner Days	Total Spawner Days	Harris Peak Live	Harris Tribs. Peak Live	Total[1/] Peak Live	Harris Peak Live & Dead	Harris Tribs. Peak Live & Dead	Total Peak[1/] Live & Dead	% Observed[2/]
1980	Petersen[3/]	2,360	(41)	2,120	2,651	3,736	1,576	5,312	139	77	216	169	97	266	22.5
1981	Petersen[4/]	961	(91)	918	1,050	1,018	1,023	2,041	42	50	92	42	52	94	21.2
1982	Petersen[5/]	2,197	(90)	2,140	2,257	4,020	2,377	6,397	166	136	302	172	147	319	29.1
1983	Total Count[6,7/]	5,569	(100)			15,062	7,367	22,429	447	330	777	625	345	970	40.3

1/ Peak live and peak live & dead counts are not adjusted for visibility.

2/ (Total spawner days/10-day ave. redd life)/Estimated total adult return.

3/ System was sampled for mark ratio entire season.

4/ Possible escapement prior to placement of weir, system sampled for mark ratio entire season.

5/ Weir washed out late in season, system sampled for mark ratio after washout only. Stratified estimate did not provide a reasonable number (<actual number handled).

6/ Weir did not wash out and was in place prior to and after adult migration.

7/ Preliminary data.

From Table 1 it is apparent that all estimators, including peak live counts, peak total counts, and escapement curve areas, correlate reasonably well with actual adult returns. The lowest return (961) in 1981 corresponded with the lowest peak live and peak total counts and escapement curve area (spawner days) for all index areas. The highest counts in all index areas also corresponded with the highest escapement of 5,569 in 1983. The estimated returns in 1980 and 1982 had overlapping confidence limits and roughly comparable values were obtained for index estimators.

The ideal index area would be one in which the proportion of spawners utilizing it remains constant each year. Therefore, the index estimation method which shows the least variation would give the most accurate relative measure of escapement. A comparison of the various escapement estimators is shown in Table 2. In this table, each estimator was divided by the estimated adult return to allow comparison between years. Peak live counts in all indexes (Harris plus tributaries) showed the least variation as an estimator with a range of ± 21% about the mean. The escapement curve area (spawner days) for the Harris index showed the most variation ranging from -41% to +51% from the mean. In general, the greatest variation occurred using escapement curve methodology and the least variation using peak live counts. It will be interesting to see if the above relationships hold true when additional data are available. Intuitively, one would expect that escapement curve methodology would give more precise escapement estimates in the long run because it accounts for multiple peaks and both short and extended run timing.

One interesting thing to note for the Harris index is that as the adult return increases so does the percentage of fish accounted for in the index area. This is a potential problem with an index system which assumes that distribution does not change significantly with the magnitude of the adult return or under varying environmental conditions. The tributary indexes, however, did not show the same trend.

It is also evident from the data that the selection of a particular "base year" escapement can have dramatic effects on escapement estimates. For example, assume that 1981 was selected as the base year with a known escapement of 961 coho and "spawner days" for Harris Creek plus the tributaries were used as an estimator. From Table 1, the calculated escapement for 1983 would be:

$$\frac{\text{22,429 spawner days in 1983}}{\text{2,041 spawner days in 1981}} \times 961 = \text{10,561 estimated escapement in 1983.}$$

Since the actual escapement was 5,569, the 1983 escapement would have been overestimated by 90%. If, however, 1982 was selected as the base year, the estimated 1983 escapement would have been:

Table 2. Variation in coho spawner days (escapement curve area) peak live, and peak total (live plus dead) counts as a percent of the total estimated return on Harris Creek 1980-1983.

Return Year	Est. Total Adult Return	Harris Spawner Days Est. Return	Harris Tribs. Spawner Days Est. Return	Total Spawner Days Est. Return	Harris Peak Live Est. Return	Harris Tribs. Peak Live Est. Return	Total Peak Live Est. Return	Harris Peak Live & Dead Est. Return	Harris Tribs. Peak Live & Dead Est. Return	Total Live + Dead Est. Return
1980	2,360	1.58	.67	2.25	.059	.033	.092	.072	.041	.113
1981	961	1.06	1.06	2.12	.044	.052	.096	.044	.054	.098
1982	2,197	1.83	1.08	2.91	.076	.061	.137	.078	.067	.145
1983	5,569	2.70	1.33	4.03	.080	.060	.140	.112	.062	.174
80-83 $\bar{X}$		1.79	1.04	2.83	.065	.051	.116	.077	.056	.133
% range about $\bar{X}$		- 40.8 + 50.8	- 35.6 + 27.9	- 25.1 + 42.4	- 32.3 + 23.1	- 35.3 + 19.6	- 20.7 + 20.7	- 42.9 + 45.5	- 26.8 + 19.6	- 26.3 + 30.8

$$\frac{\text{22,429 spawner days in 1983}}{\text{6,397 spawner days in 1982}} \times 2{,}197 = \text{7,703 estimated escapement in 1983.}$$

Using this base year, actual escapement would have been over-estimated by 38%.

Ideally, actual basin-wide escapements should be precisely determined by adult tagging studies conducted over several base years so that varying flow conditions and escapement levels are experienced. Then a relationship can be formulated between index counts and a range of actual escapements that will improve the accuracy of escapement estimates. If only a single base year is used, however, it should be a year where escapements and flows were about "average" and not at the extremes.

It is clear that more evaluation of coho indexing is needed. The limited data from the Harris Creek study show the potential variability (40% to 90%) that can exist in estimating coho escapements for one stream. The actual variation when a number of index areas in several streams are used to estimate escapement to an entire river basin is unknown. As a start, similar studies should be conducted on a number of different stream types to help evaluate the stream indexing system.

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SAMPLING STRATEGIES FOR ESTIMATING COHO ESCAPEMENT

by

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SAMPLING STRATEGIES FOR ESTIMATING COHO ESCAPEMENT

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Accurate estimates of wild salmon escapement are one of the most pressing data needs of managers of salmon stocks in western Washington, USA. This paper considers a possible sampling structure for estimating salmon escapement based on experience with coho stocks of the Quillayute River system located on the Olympic Peninsula. The distinction between sample design and sample estimator, as well as the incorporation of auxiliary information for stratification, design, and estimation leads to a large set of sampling strategies that a manager can select from on the basis of prior knowledge, practicality, and desired accuracy and precision.

I. Introduction

Accurate estimates of the number of fish that escape to spawning grounds and the number of redds built are essential to ocean and in-river salmon management. The objective of this report is to consider possible methods of estimating the number of coho redds built each season.

Two important uses of these numbers are determining run size and developing and monitoring spawner-recruit relations. Run size for a particular stock is determined by simply summing the catch of that stock by intercepting fisheries and escapement. It is important that estimates of these two components be unbiased or at least the order of the bias be known and that some estimate of the variance is available. Knowledge of the magnitude of error in the run size estimate could be valuable in modeling applications. For spawner-recruit analysis estimates of the number of redds built and the consequent return of that resulting cohort is necessary. Estimates of escapement form a basis of both the domain and range of the spawner-recruit function.

Description of the Problem

The problem is to estimate the number of coho (Oncorhynchus kisutch) redds built throughout a river system. The Quillayute River system, located on the west side of the Olympic Peninsula between $47^{\circ}30'$ and $48^{\circ}10'$ latitude and $123^{\circ}30'$ and $124^{\circ}40'$ longitude, has provided the background information for this report and will be used for specific examples, but general concepts should apply to other coho stocks on other river systems.

The Quillayute system has a drainage area of approximately 1630 km^2 and consists of four river systems, the Dickey, the Soleduck, the Bogachiel, and the Calawah. Based on field biologists' experience with spawning ground surveys, up to 270 kilometers of streams, primarily tributaries, in the Quillayute system are used for coho spawning. Redd building by fall coho takes place over a time interval of 2 to 3 months, approximately. Two immediately apparent difficulties in tallying the number of redds built are the extensive mileage base and the lengthy time period. A third difficulty is measurement problems: actually seeing, counting, and not double-counting redds can be very difficult.

Sampling, spatially and temporally, the streams throughout the system is a necessity given typical manpower constraints and practical considerations. Sampling, of course, introduces another source of error, and additional consideration of the trade-offs between time and money savings and the magnitude of sampling error must be made.

Escapement estimation: history and current knowledge

Spawning ground surveys were begun on the Quillayute system by the Washington Department of Fisheries starting in 1974 and the Quileute Indian Fisheries Department began their surveys in 1979. Since 1979 both agencies have worked cooperatively in the information gathering process using the methodology described below.

Quite briefly, the current methodology consists of visiting several stream sections throughout a river system on a regular basis during the spawning season, noting the number of redds built in each section and distinguishing between redds built since the last visit, "new" redds, and those built prior to the last visit, "old" redds. The field crew distinguish between "old" and "new" redds by tying flagging to available permanent objects located near a redd observed for the first time; measurements of the total number of redds built throughout the spawning season, cumulative redds, are thus possible. Another generally much larger, set of sections is visited once (occasionally twice), usually in the middle of the season, and the number of redds visible at that point in time are recorded. The two sets of stream sections are called index and supplemental streams, respectively.

Using information from index streams as to the average ratio between redds visible at the time of the survey of supplemental streams and the total or cumulative redds built, the cumulative redds for the supplemental streams are estimated. The cumulative redds for the remaining set of stream sections never visited, but whose mileage length is known, are estimated using the average cumulative redd per kilometer ratio observed on the index and supplemental streams.

Total redds = Index stream redds + Estimated supplemental stream redds

+ Estimated unvisited stream redds

For additional details of this methodology see Anon. (1980).

As a result of these efforts, several observations have been made:

1. Differential preferences for redd building exist between rivers within the Quillayute system. Eg., the Soleduck River and its tributaries and the Dickey River and its tributaries have an equal mileage base in terms of utilized coho spawning habitat, but the Soleduck has consistently higher redd densities.

2. Redd building activities are a fairly continous process, but not uniformly so; unimodal distributions in the number of redds built over time are common, but, of course, this is greatly affected by the preceding in-river fisheries.

3. Redd life, or the length of time during which a redd is visible to a trained observer, can be quite variable between rivers as a result of differential flow rates, water clarity, and scouring problems.

Various problems with the current method as applied to the Quillayute system include:

1. Some index streams are chosen deliberately on the basis of historically high redd densities. One reason for this has been the psychological discouragement experienced by field personnel when observing few, or even zero, redds week after week after making often difficult treks to remote stream sections. However, the estimator used does not account for atypical sections and is consequently biased upwards.

2. In practice, for supplemental streams that had no visible redds when visited, the ratio estimate based on the index streams, which would yield an estimate of zero, is sometimes not applied. Instead, because of the intuition that redds were indeed built at sometime that season, somewhat arbitrary estimates of redds per kilometer are used. This is a consequence both of problem 1 and the use of a ratio estimator.

3. Estimates of the variance of the point estimate can not be easily made without making major assumptions about the distribution of redds in the river system.

Limitations of this report

The aim of this report is to consider various sampling strategies for estimating total coho redds and the variance of the estimate while employing the current field procedures used for tallying cumulative redds. Consideration is given to practical time and money constraints, but decision making procedures for choosing an optimal strategy are not addressed. Estimating the number of fish or adults is not dealt with either (the current practice is to assume two adults per redd), nor is the problem of measurement error discussed. Other areas needing additional work are discussed at the end of this report.

II. A Sampling Framework: General and Specific

The terminology used in this paper primarily follows Cassel *et al.* (1977) with slight modifications and should be defined for clarification. The central terms are universe (U), populations (W, X, Y,...), and parameters (θ_1, θ_2,...). The universe is the finite set of entities, sometimes identifiable and sometimes not, that possess characteristics of possible interest. Any particular characteristic of interest defined on the universe is called a population. To each member of the universe is associated one or more characteristics, i.e., more than one population can be defined on the universe. A parameter is a function of a population, such as a mean or total. Let θ represent an arbitrary parameter and $\hat{\theta}$ an estimate of the parameter. Upper case letters will be used to denote a characteristic for an entire set and lower case letters will be used to denote individual elements of the set; e.g., Y for the universe and y_i for element i.

Other useful concepts are sampling design, sampling estimator, and sampling strategy. The sampling design is the mechanism or procedure for selecting a subset or sample of the universe. The sampling estimator is the mechanism or function, based on the sample, used to estimate a parameter for the population of interest. The sampling strategy is the combination of a sampling design and sampling estimator.

The Structure of the Escapement Problem

For this problem view the universe as the collection of stream sections of the river system where spawning takes place. Each particular stream section is a member of the sampling universe. Note that the identification of the universe in this case is somewhat arbitrary, because the system could be partitioned an infinite number of ways; this is discussed briefly at the end of the report.

With each universe member, u, one might imagine at least four characteristics or populations:

1.	Number of cumulative redds	y
2.	Manager's "best guess" of cumulative redds prior to sampling	w
3.	Number of visible redds at time t	$x(t)$
4.	Length of stream section in kilometers	z

The goal, restated in this framework, is to estimate the parameter, $\sum_{U} y$ or the total number of cumulative redds for the entire universe. Y is the population or variable of interest, and W, X(t), and Z are auxiliary populations. Note that the auxiliary variable X(t) is somewhat unusual relative to standard situations in that knowledge of its value follows selection of index streams that yield y (except when t=0); this means that X(t) is of value for estimation, but not design. Also, note that the use of auxiliary population W might be viewed as a Bayesian procedure incorporating subjective or prior information. Z is assumed known for all U, but this number may increase with additional information each year.

III. Potential Sampling Strategies

Several potential sampling strategies are described below; the strategies are arranged on the basis of computational complexity, from simplest to most complex. Details of the point estimates and the estimates of the variance are given in Appendix A. Brief comments on the practical utility of each design are given, also, with a more general discussion in the next section.

Let SRS denote simple random sample and PPS denote probability proportional to size.

1. SRS Design and Sample Mean Estimator. Several (n) streams are chosen at random from the universe. These streams are index streams; cumulative redds, y, are recorded and the estimate of the population total is $N\bar{y}$.

Note that no supplemental streams are used, i.e., no auxiliary information is incorporated. Depending on the variability of y between stream sections and the desired precision, this method could be very expensive.

2. SRS Design and Linear Regression Estimator. Again n index streams are chosen at random and X(t) and y are recorded. All the remaining N-n streams then become supplemental streams that are visited at or near time t and visible redds, X(t), are recorded. A linear regression of y on x(t) is fit using the n index stream observations. The estimate of the population total is $N \cdot (b + b\,\bar{x}(t))$, where $\bar{x}(t)$ is the mean visible redd count at time t for the entire universe.

Simple variations on this idea include using a ratio estimator instead of a regression estimator or using a multiple regression estimate incorporating other auxiliary populations such as z or w. Note that if the index streams were selected deliberately on the basis of high redd densities, but had otherwise typical redd life (y - x(t) relationship representative), then a multiple regression incorporating z would help diminish some of the bias in the intercept.

This strategy requires sufficient manpower to cover a system or stratum in a short time period in order to record x(t) and may be impractical on large systems.

3. Double SRS Design and Linear Regression Estimator. A simple random sample of size n' is selected and from that a random subsample of size n is chosen. The subsample becomes the set of index streams and the remaining n' - n streams are supplemental streams. Again, as in strategy 2 a linear regression of y on x(t) is fit using the index stream information. The estimator is then $N \cdot (b + b\,\bar{x}'(t))$, where $\bar{x}'(t)$ is the mean of the n' streams.

Again this strategy can be modified by substituting ratio or multiple regression estimators.

This strategy is simply a scaled-down version of the previous one and may be suitable for large systems where complete supplemental stream coverage is impossible.

4. Variable Probability Design (ppsΣw) and Ratio Estimator (Lahiri). There are several ways of implementing this design, but a very simple procedure is to draw the first element with probability of selection for element i equal to $w_i/\Sigma w_i$. Then take a simple random sample of size n-1 from the remaining N-1 elements. These n streams are then index streams. The estimator is $N \cdot \bar{w}_n(\bar{y}_n/\bar{w}_n)$ or a ratio of the means estimator.

This strategy would be fairly easy to implement and requires no supplemental streams, but as will be discussed in the next section its value is dependent upon the relationship between "best guesses" and actual values.

IV. Discussion

Although only four strategies were listed, if the manager keeps the distinction between design and estimator clear, then the set of possible

strategies increases greatly, e.g., fixed and variable probability designs, auxiliary information used in designs and in estimators. The choice of any particular strategy will depend upon the physical nature of the river system, the prior knowledge of the manager, time and money constraints, and the desired accuracy and precision.

A conventional approach for evaluating strategies is to estimate the cost of achieving a desired precision for each strategy. This report, however, will make only some general statements in regard to strategy selection based on practical and technical criteria.

Practical Considerations

The most time consuming and, consequently, expensive portion of the process of estimating total redds is determining y or cumulative redds from the index streams. Time and money considerations again come into play for those strategies that use supplemental streams. A complication in estimating the cost of an index or supplemental stream is the fact that accessibility of the stream sections varies considerably, making some streams much more difficult to visit than others. One possibility for diminishing the accessibility variation is to restrict the randomization to a subset of the universe. The critical assumption for this procedure would be that the parameter values for both subsets are equal.

Systematic sampling may be preferable to simple random sampling to avoid the possible clustering, spatially, of the sample units or index streams. If the universe members or streams sections are not labeled or easily identifiable, then systematic sampling may be preferable, also. Theoretically, a systematic sample and a simple random sample should yield equally precise and unbiased estimates if y is thought to be distributed randomly from stream section to stream section. Further, if it is thought that a linear trend in y exists across the universe sequence, or in this situation as one moves upstream, then a systematic sample may yield a more precise estimate. For more details as to the technical advantages and disadvantages of a systematic sample see Cochran (1977, Chapter 8).

On larger river systems stratification for logistic purposes alone may be desired; e.g., visiting a large number of supplemental streams in a short time interval may be impractical. Technical motivations for stratification are given in the next section.

Technical Considerations

Technical criteria for evaluating strategies might be to compare the accuracy and precision of the resulting estimates over the range of possible outcomes. Accuracy is usually expressed in terms of bias, while precision is measured by variance. A useful measure that is a function of both is mean square error, MSE. These measures defined mathematically:

$$\text{Bias} = E(\hat{\theta}) - \theta$$
$$\text{Variance} = E(\hat{\theta} - E(\hat{\theta}))^2$$
$$\text{MSE} = E(\hat{\theta} - \theta)^2 = \text{Variance and } (\text{Bias})^2$$

E is the expectation or the sum over the range of possible samples of the probability of each sample, p_s, times the resulting estimate, $\hat{\theta}$, or $E(\hat{\theta}) = \Sigma p_s \hat{\theta}$. Such a definition of expectation that relies only on the existing universe is consistent with the sampling theory known as the finite population model; and the resulting bias, variance, and MSE are called design bias, design variance, and design MSE, respectively. An alternative approach known as the superpopulation model considers the existing universe as just one realization of several possible outcomes and leads to a definition of expectation identical to that of classical statistical theory. Any estimator unbiased under the finite population model is also unbiased under the superpopulation model (see Cassel et al., 1977 and Cochran, 1977).

The sample mean and the Lahiri ratio estimator are unbiased under their respective designs, while the regression estimator (and ratio estimator) for the remaining two strategies are biased under the finite population model. Cochran, (1977) shows that the bais of the regression and ratio estimators is of order 1/n. Under the superpopulation model if an "underlying" linear relation exists between cumulative redds and an auxiliary variable, then the regression or ratio estimator are unbiased. See Appendix B for procedures to estimate regression or ratio coefficients under certain superpopulation models.

The size of the variance of the estimators is a function of sample size for all strategies and a function of the relationship between an auxiliary population and the population of interest for the last three strategies. As sample size increases the variance decreases. Therefore, given any particular strategy and knowledge of the variation of the estimator around its mean, one can estimate the appropriate sample size for a desired degree of precision. The general procedure is to solve for n, which is found in the variance, in the following equation:

$$L = 2\, t_{\alpha/2} \sqrt{\text{Variance of estimator}},$$

where L = desired width of $1-\alpha$ confidence interval

$t_{\alpha/2}$ = value of t-statistic with $\alpha/2$ probability above that point.

The second possible influence on the variance, the relationship between an auxiliary variable and Y, is much more difficult to ascertain and complicates the choice of an optimal strategy. Speaking generally, auxiliary information can be incorporated at the design stage, the estimation stage, or both. Incorporation at the design stage includes not only variable probability designs, but also includes stratification, which is discussed in the next paragraph. Strategy 4 uses an auxiliary population at both the design and estimation stage, while strategies 2 and 3 do so only at estimation stage. Whether the use of auxiliary information at either stage leads to an improved estimator, i.e., lower variance or MSE, depends primarily on the strength of the relationship between the auxiliary variable and Y. In general, the closer the relationship, the greater the decrease in variance. E.g., Cochran (1977, p. 157) shows that a ratio of the means estimator in a simple random sample design has a lower MSE than a sample mean estimator if

$\rho \geq$ CV of X/ 2(CV of Y)

Where ρ = population correlation coefficient between auxiliary population, X, and Y,
CV = coefficient of variation.

The relationship between peak visible (approximate) and cumulative redds for index streams on the Quillayute system rivers for a three-year period is shown in Table 1. Note that ratio estimates are more precise than sample mean estimates for each river each year by Cochran's criteria. Similar inequalities can be shown for regression estimators versus sample mean or ratio estimators. Large sample results (Cochran, 1977) indicate that if the correlation coefficient is not equal to zero, a regression estimator is more precise than a sample mean; and if the y-intercept is not equal to zero, it improves upon a ratio estimator, also. For small samples, however, the superiority of regression estimators over ratio estimators is questionable; also note that for the escapement problem the regression intercept must be greater than zero.

Table 1. Relationship between peak visible redds (X) and cumulative redds (Y) for index streams in Quillayute River system, 1980-83.

Year	River	CV_x	CV_y	$\hat{\rho}$	$CV_x/2CV_y$	n	Time of Peak
1980	Bogachiel	.70	.70	.99	.50	6	Dec. 18
	Calawah	.85	.79	1.00	.50	3	
	Dickey	.39	.42	.96	.46	5	
	Soleduck	.19	.20	.68	.48	6	
1981	Bogachiel	.49	.44	.97	.56	4	Dec. 18
	Calawah	.58	.60	.94	.48	6	
	Dickey	.94	.73	1.00	.64	3	
	Soleduck	.30	.38	.86	.39	4	
1982	Bogachiel	.34	.47	1.00	.36	3	Dec. 9-10
	Calawah	.36	.36	.94	.50	3	
	Dickey	.27	.17	.99	.79	3	
	Soleduck	.43	.39	.91	.55	4	

Cochran (1977, pp. 341-342) also compares strategies 1 and 3 on the basis of the correlation coefficient and the relative cost of the large sample units and the subsample units, in this case supplemental streams versus index streams. Finally, the Lahiri estimator has been shown to be optimal or at least very good in several theoretical and empirical situations (Cassel et al., 1977). There are a myriad of strategies to choose from, as was stated earlier, but consideration of these four strategies should provide a good starting point for a manager dealing with his particular river system.

Stratification, or partitioning the universe, U, into r distinct subsets $U_1, U_2, \ldots, U_r$, can be done for all four strategies. The individual stratum point estimates and variance estimates are simply summed to yield point and variance estimates of the total cumulative redds for U. The

technical advantage of stratification arises if the variance for the stratified estimate is less that that for the unstratified estimate. Generally, if the variability between an estimator and the parameter of interest is less within the strata than between strata, then stratification is recommended. E.g., if the relation between X(t) and Y is less variable within rivers than between rivers, because of different flow rates, say, then stratification by rivers should yield a more precise estimate for strategies 2 and 3.

Conclusions

Although the above comments are very general and actual field data from the Quillayute system are quite limited, some specific comments can be made. On the basis of observations from the Quillayute system, the variability of cumulative redds is great enough that incorporating information from any of the three aforementioned auxiliary populations at either the design or estimation stage should yield a more precise estimate than strategy 1. Secondly, X(t) or W are probably more closely related to Y than is Z, because the number of redds observed at time t or the historical abundances (that W should reflect) should be more closely related to cumulative redds than is the stream length. Thirdly, if using X(t), selecting t_o such that $X(t_o) \geq X(t)$ for all other t, i.e., $X(t_o)$= peak visible redds, appears to maximize the correlation between X(t) and Y and consequently reduces the variance. Finally, if the anticipated reduction in variance from using a regression estimator in strategy 2 or 3 is considered small relative to the bias of order 1/n, then strategy 4 may be best: it is unbiased, easy to implement, incorporates auxiliary information, and has proven optimal under broad theoretical models.

Generally, the larger the system and/or the more limited the budget, the more likely strategies 3 and 4 would be preferred over strategies 1 and 2. Strategy 3 incorporates "current" auxiliary information at the estimation stage as does strategy 2, but requires a less complete supplemental coverage. Strategy 4 is even less field intensive than strategy 3 because only index streams are used. A slight variation on strategy 4 would be to select individual index streams with probability proportional to W_i, rather than a set of index streams with probability proportional to Σw_i. This variation would diminish some of the psychological discouragement of visiting low productivity index streams by making their probability of selection low, but the implementation of such a design is much more difficult (Cassel et al., 1977, pp. 16-17).

V. Future Work

The escapement problem can be dichotomized as a problem of estimating escaping fish and a problem of estimating redds. For counting fish, technological advances in electronic fish counters may make sampling obsolete; careful consideration of this possibility must be made, although for the especially dynamic Olympic Peninsula rivers fish counters have had limited success. If electronic fish counters are not everywhere successful and estimates of redd counts are made instead, then one is still faced with the problem of expanding the number of redds to the number of adults. The accuracy of the current adult-to-redd ratio of two needs to be examined. If

the preceding fisheries are selective with respect to sex, the ratio is suspect. If the magnitude of error of this ratio is large, refinements in sampling strategies to estimate redds might be of quite limited value.

With regard to the problem of estimating redds, the major concern is to develop objective procedures for rating strategies so as to allow a manager a means of selecting the "optimal" strategy. Practicality, accuracy, and precision are three criteria discussed in this paper that could serve as the basis for selection. Cost and precision would be functions of sample size for both index and supplemental streams. A final problem is to determine an objective procedure for partitioning a river system into stream sections or universe members, the problem being somewhat similar to determining appropriate experimental unit sizes in experiment design.

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Appendix A

Estimates of totals and variances for the four sampling strategies

Variance formulae for strategies 1-3 can be found in Cochran (1977) and for strategy 4 in Sen (1953).

Let N = the number of stream sections in the river system
Let $Y = \Sigma\, y_i$ or the population total and for simplicity view Y and Var(Y) as estimates, not parameters, in the following equations.

1. SRS Design and Sample Mean Estimator.

Randomly select n index streams with equal sample probabilities and observe y.

a. $Y = N\,\bar{y}$, where $\bar{y} = (\sum^{n} y_i)/n$

b. $\mathrm{Var}(Y) = N^2\,(1/n)\,(1-n/N)\,(1/(n-1))\,\sum^{n}(y_i - \bar{y})^2$

2. SRS Design and Regression Estimator.

Randomly select n index streams with equal sample probabilities and observe y and x(t). Visit all remaining N-n streams (supplementals) and observe x(t).

a. $Y = N\,(b_o + b_1\,\bar{X}(t))$,

where b_o and b_1 are the sample regression coefficients found by regressing y on x(t) from the index streams and $\bar{X}(t)$ is the population mean of x(t).

b. $\mathrm{Var}(Y) = N^2\,(1/n)\,(1-n/N)\,(1/(n-2))\,\sum^{n}(y_i - b_o - b_1\,x_i(t))^2$.

This estimate of variance has a bias of order 1/n.

3. Double SRS Design and Regression Estimator.

Randomly select n' supplemental streams and observe x(t), then take a simple random subsample of size n and observe y; i.e., there are n index streams and n'-n supplemental streams.

a. $Y = N\,(b_o + b_1\,\bar{x}'(t))$,

where b_o and b_1 are subsample regression coefficients and $\bar{x}'(t)$ is the mean of x(t) for supplemental and index streams.

b. $$\mathrm{Var}(Y) = N^2\left\{s^2_{yx}\left[1/n + \frac{(\bar{x}'(t) - \bar{x}(t))^2}{\sum^{n}(x_i(t) - \bar{x}(t))^2}\right] + \frac{s^2_y - s^2_{yx}}{n'} - s^2_y/N\right\}$$

where $s^2_{yx} = 1/(n-2)\,\left(\sum^{n}(y_i-\bar{y})^2 - b_1\sum^{n}(x_i(t)-\bar{x}(t))^2\right)$

$s^2_y = 1/(n-1)\,\left(\sum^{n}(y_i-\bar{y})^2\right)$.

Cochran (1977, p.343) gives two variance estimates; the one above is recommended if the subsample is small and terms in 1/n are not negligible relative to 1.

4. Variable Probability Design (ppsΣ w) and Ratio Estimator (Lahiri).

Select the first index stream with probability $w_i/\Sigma w_k$ for i=1,2,...,N and take a simple random sample of size n-1 from the remaining N-1 streams, recording y on all streams.

a. $Y = N(y_n/w_n)\,W_N$

b. $$\mathrm{Var}(Y) = \sum_i^n \sum_j \left[(a_i a_j - a_{ij})/a_{ij}\right]\left[(y_i/a_i - y_j/a_j)^2\right],$$

where $a_i = (N-n)/(N-1)\ (w_i/\Sigma w_k) + (n-1)/(N-1)$,

$$a_{ij} = (n-1)/(N-1)\left[(N-n)/(N-2)\ (w_i/\Sigma w_k + w_j/\Sigma w_k) + (n-2)/(N-2)\right].$$

This estimate of the variance is unbiased and always positive.

Appendix B

Linear estimators for particular superpopulation models

The simplest mathematical relationship between two variables, say X and Y, where Y=f(X), is a line. When constructing a sampling estimator based on an auxiliary population, X, one must decide whether a linear relationship is appropiate,first,and whether a ratio (Y=RX) or a regression ($Y=B_o + B_1X$) estimator is more appropiate, second. Graphing the observations and/or theoretical considerations provide a basis for making these decisions.

Under the superpopulation model approach which views the relationship between Y and X as stochastic, i.e., $Y=f(X) + \varepsilon$, where $\varepsilon \sim N(0, k\,\sigma^2)$, weighted least square estimators are considered optimal with respect to accuracy and precision. Again plotting Y against X should be helpful with this problem, i.e., deciding what value of k seems reasonable. Note that for the ratio model values of k=1 or 2 lead to the ratio of the means estimator and the mean of the ratios estimator, respectively.

RELATIONSHIPS BETWEEN VISUAL COUNTS OF COHO SALMON (ONCORHYNCHUS KISUTCH) FROM SPAWNING FISH SURVEYS AND THE ACTUAL NUMBER OF FISH PRESENT

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ABSTRACT

Relationships between the number of adult and jack coho salmon *(Oncorhynchus kisutch)* observed per mile on spawning fish surveys and the estimated number of coho present per mile were developed. The effects of several habitat features were also examined. On the average surveyors observed 75.5% of the adult coho and 47.8% of the jack coho present in the survey sections. The percentage of the coho observed did not vary with spawner density. There was no significant difference between the percentages of coho salmon observed before and after the date of peak spawning. However, there was a trend to see a larger percentage of the adult coho after the date of peak spawning.

INTRODUCTION

To index the escapement of wild coho salmon *(Oncorhynchus kisutch)* to Oregon's coastal basins, the Oregon Department of Fish and Wildlife (ODFW) conducts spawning fish surveys of coastal streams each fall and winter. Since coho tend to spawn in small headwater streams, where they can be relatively easily observed, the surveys are made on foot. The surveyors walk along or in the streams where the salmon are spawning and count the number of jack and adult coho observed. The results of these surveys are used to establish an index of spawning escapement calculated as the number of spawning fish per mile of index stream.

Beidler, Nickelson and McGie (1980) used the spawning survey information as one method of estimating the optimal escapement for Oregon's coastal coho. Nickelson (1980) described the need for ODFW to obtain an actual escapement estimate instead of the index system presently used to estimate coastal coho escapement. These reports also revealed that little information on the accuracy of the spawning survey methodology for coho salmon was available. Willis (1964) analyzed the results of standard spawning surveys conducted on foot on three streams by three surveyors on three consecutive days. He found no significant differences between the counts of the three surveyors or between the counts grouped by time of day. Beidler and Nickelson (1980) reviewed the history and development of Oregon's spawning fish surveys and made recommendations for improving its reliability. The recommendations recognized the need to evaluate the assumptions of the spawning fish survey technique and to determine how accurate the methodology is at estimating the actual number of coho salmon present in a survey section. This information would make it possible to adjust the spawning survey data for any observational bias or systematic error.

This paper reports the results from two seasons of field work designed 1) to determine the relationship between the number of coho salmon observed on standard surveys and the number actually present, 2) to determine the relationship between the percentage of salmon observed and spawner density and 3) to investigate the effects of several habitat features and environmental variables on these relationships. This report includes only the data on coho salmon; however, information was also collected on chum salmon *(O. keta)* and chinook salmon *(O. tshawytscha)*.

METHODS

The study streams were selected to represent the range of the coastal habitat available for coho spawning in Oregon. The eight streams surveyed during the 1982-83 sampling season were located in the Alsea and Yaquina basins. The 22 streams surveyed during the 1983-84 sampling season were distributed from the Tillamook basin in the north to the Coquille basin in southern Oregon. The section locations were determined by surveying streams and identifying where coho were present.

Between October and January a standard spawning survey was conducted on a section of stream ranging from approximately 200 m to 800 m in length. The section length was determined by where we could place nets to prevent salmon from entering or leaving the section. The surveyor walked the stream between the nets and recorded the species and the number of adult and jack salmon observed. In addition, the surveyor recorded the visibility and stream flow conditions. Visibility was rated 1, if the bottom of deep pools was visible, 2 if the bottom in riffles but not in the deep pools was visible and 3 if the bottom of riffles was not visible. We surveyed only during conditions 1 or 2. Flow was rated as either high (3), moderate (2), or low (1). The surveyors always wore polarized sunglasses to reduce the surface glare while surveying.

The removal method (Seber and LeCren 1967) was used to estimate the population of adult and jack salmon in the section. Backpack electroshockers were used to capture the salmon, which were then held in live cages suspended in the stream. Either two or three passes were made depending on the percentage reduction between each pass. We generally made another pass if the reduction was less than 75%.

After completing the population estimates, we measured the section length to the nearest meter and along ten equally spaced transects, we measured the width to the nearest 0.1 m. At three equally spaced intervals across each width transect we measured the stream depth to the nearest 0.01 m. The width and depth measurements were averaged separately and multiplied to obtain an index of stream size.

The amount of hideable cover within survey sections was estimated by first establishing cross-sectional transects at 5.0 m intervals perpendicular to the flow. We defined hideable cover as undercut banks, logs, boulders, overhanging brush, and debris or leaves which could hide salmon from the view of the surveyor. The first transect location was

randomly established 0 to 5 m upstream of the downstream blocking net. The transect was divided into observation areas 2 m^2; 1 m upstream and 1 m downstream by 1 m wide centered along the transect line (Figure 1). We recorded the five types of hideable cover present within each observation area. If more than one type occurred the dominant type was recorded.

The percentage of each cover type for each stream section was calculated by dividing the total number of times each type of cover was identified by the total number of observations. This methodology was designed to insure that we obtained a minimum of 200 observations per survey section.

The percentage of coho observed on each survey was calculated as the ratio of the number observed to the population estimate. I expanded the number observed in the survey sections to a per-mile basis for each stream.

I used step-wise selection procedures to develop multiple linear regression equations (Draper and Smith 1966) to predict the number of jack and adult coho per mile. The explanatory variables were visibility, the index of stream size, the number of adult and jack coho observed per mile, the mean width, the mean depth, and the percentage of the individual and combined cover types. I included terms in the models if their partial t-values had an associated probability greater than 0.05.

RESULTS AND DISCUSSION

For the two years of data combined, the surveyors observed 75.5% of the adult coho and 47.8% of the jack coho present in the study sections. The average percentage of jack coho observed varied more between years than the average percentage of adult coho observed (Table 1).

Table 1. Average percentage of the estimated number of spawning coho salmon present that were observed on spawning fish surveys.

Age group, Spawning season	Surveys	Percentage observed
Adults		
1982-83	19	73.4
1983-84	32	76.6
Combined	51	75.5
Jacks		
1982-83	9	22.7
1983-84	29	53.7
Combined	38	47.8

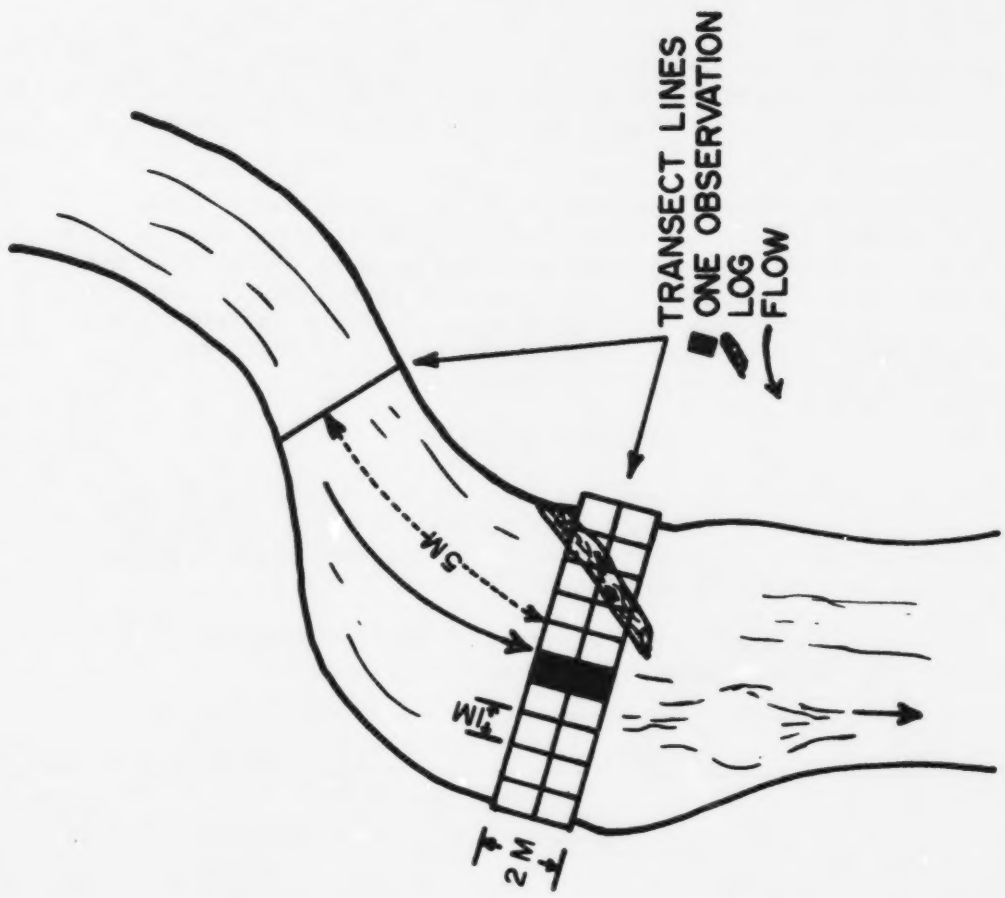

Figure 1. Transects used to sample hideable cover.

The number of coho observed per mile was the only significant variable in explaining the variation in the number of adult or jack coho present per mile (Figures 2 and 3). The number observed per mile accounted for 90% of the variation in adults and 89% of the variation in jacks (Table 2). The regression equations (Table 2) were fitted through the origin since the partial t-values for the constants were not significant ($P \geq 0.05$) and the values for the number of coho observed per mile and the population estimate were not included in the raw data set if both values were 0. For adult coho the percentage of logs (Table 3) was most closely correlated to the residuals from the model (Table 2, equation 2). Total cover, the percentage undercut banks, and visibility (Table 3) were most closely correlated to the residuals from the jack model (Table 2, equation 4).

Table 2. Equations relating the estimated number of coho salmon present per mile (y) and the number of coho salmon observed per mile (x) on spawning fish surveys.

Age group, equation form	Number	Equation	R^2	N
Adults				
With constant term	(1)	$y = 1.294(x)+0.531$	0.860	51
Fitted through the origin	(2)	$y = 1.300(x)$	0.901	51
Jacks				
With constant term	(3)	$y = 1.484(x)+5.217$	0.839	38
Fitted through the origin	(4)	$y = 1.569(x)$	0.885	38

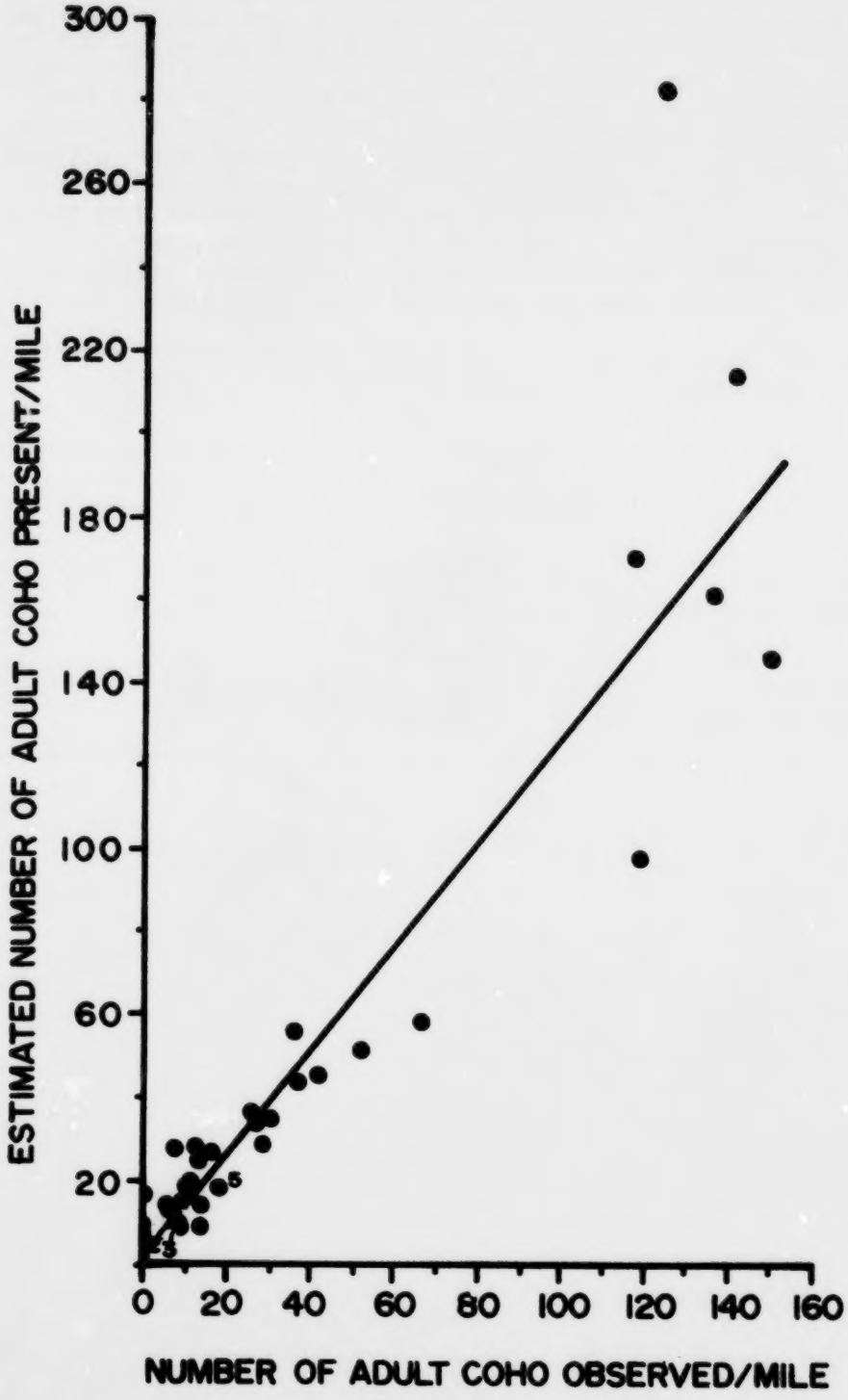

Figure 2. The relationship between the estimated number of adult coho present per mile and the number of adult coho observed per mile.

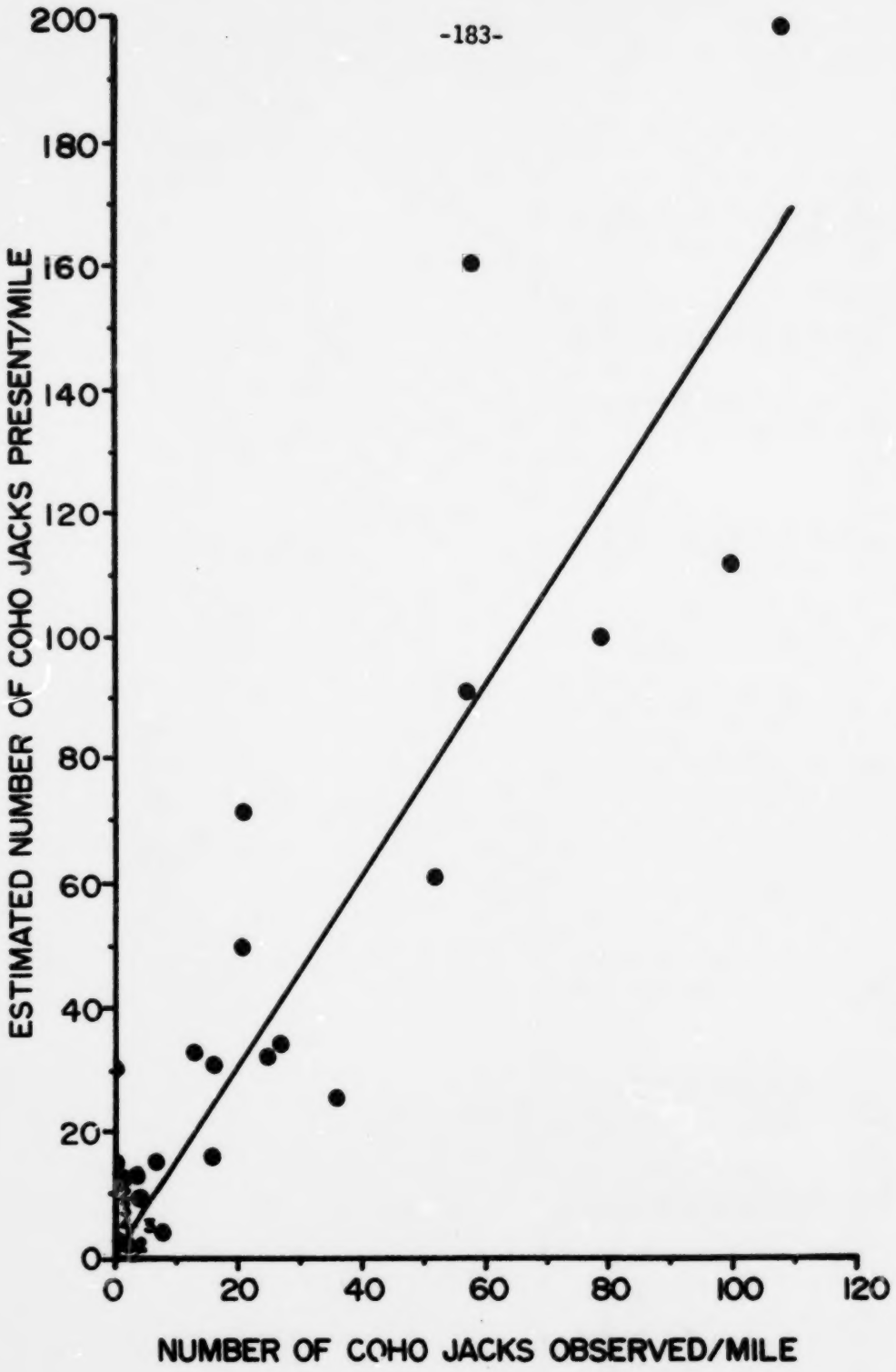

Figure 3. The relationship between the estimated number of jack coho present per mile and the number of jack coho observed per mile.

Table 3. Descriptive statistics for the habitat features and environmental variables used in the multiple regression analysis.

Variable	Adults					Jacks				
	DF	Partial-t	Min.	Max.	Mean	DF	Partial-t	Min.	Max.	Mean
Size index	46	0.09	0.5	4.7	1.9	33	1.21	0.5	4.7	1.8
Width	46	-0.02	2.8	10.7	5.6	33	1.06	2.8	10.7	5.2
Depth	46	0.28	19.0	62.0	33.9	33	1.48	19.0	62.0	32.7
Visibility	46	-0.02	1.0	2.0	1.2	33	1.78	1.0	2.0	1.3
Total Cover	46	0.28	3.9	36.5	19.1	33	1.82	3.9	36.5	19.9
Undercut banks	46	-0.26	0.8	21.2	8.5	33	1.80	0.8	21.2	8.9
Logs	46	1.10	1.5	14.2	6.6	33	1.25	1.5	14.2	6.7
Overhanging brush	46	0.05	0.0	9.1	2.1	33	1.69	0.0	9.0	2.4
Debris & leaves	31	-0.20	0.0	11.5	1.8	25	0.96	0.0	11.5	2.1
Boulders	31	-0.33	0.0	7.2	0.6	25	0.10	0.0	1.3	0.4

The model should be better suited to adjust survey counts on a spawning season basis rather than on an individual survey basis due to the larger cumulative error associated with the more frequent adjustments. The number observed per mile ranged from 0 to 107.9 for jacks and to 161.0 for adults. Adjustments should not be made for values larger than these since they are beyond the range of the models. Adjusting the counts of spawning surveyors for the observational bias associated with foot surveys, is the first step toward the development of a technique to estimate (rather than index) escapement as recommended by the Coho Salmon Plan (Oregon Department of Fish and Wildlife 1982).

No significant relationships between the percentage of adult or jack coho observed and the estimated number present per mile were evident. This suggests that the surveyors observed a constant percentage of the number of coho present over the range of spawner densities observed.

Some surveyors suggested that they may see a larger percentage of the total number of coho present as the fish sexually matured and passed the date of peak spawning. The date of peak spawning, as determined from index surveys in the same basin, was used to classify the verification surveys as either before or after the estimated date of peak spawning. The difference between the average percentage observed before the date of peak spawning and the average percentage observed after the date of peak spawning was not significant ($P \geq 0.05$) (Table 4). However, there was a tendency to observe a higher percentage of adults after the peak for the two years of data combined. There was more variation between years in the percentage of jacks observed before and after peak spawning but no general trend was evident.

Table 4. Average percentage of the estimated number of spawning coho salmon present that were observed on spawning fish surveys before and after the date of peak spawning.

Age group, Spawning season	Before peak		After peak	
	Surveys	Percentage	Surveys	Percentage
Adults				
1982-83	7	57.4	11	86.0
1983-84	11	80.8	18	85.2
Combined	18	71.6	29	85.5
Jacks				
1982-83	5	12.5	6	33.3
1983-84	13	65.3	13	51.3
Combined	18	55.3	19	45.6

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SITE CHARACTERISTICS FOR BENDIX SIDE SCAN SONAR DEPLOYMENT IN UPPER COOK INLET, ALASKA

by

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INTRODUCTION

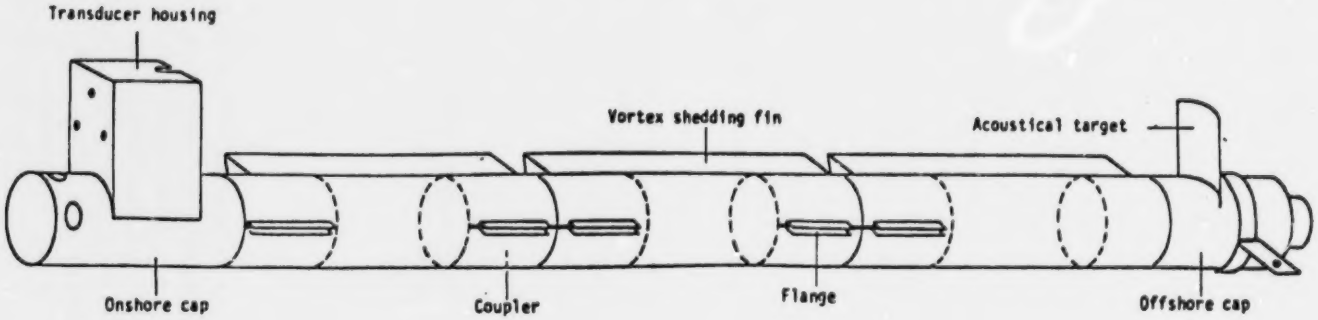
Assessing the return of salmon species to Upper Cook Inlet, Alaska is complicated by the presence of mixed species and mixed stocks with overlapping run timing. Because of the complexity of the return, management of the sockeye salmon (Oncorhynchus nerka) fishery (average harvest of 1.2 million fish) currently integrates information received from a variety of programs including off-shore test fishing, scale pattern analysis, district test fishing, comparative analysis of commercial harvest and effort levels (CPUE), and in-river enumeration of returning spawners. These programs are designed to allow fisheries managers to optimize escapement and commercial catch by harvesting different proportions of the return to each river. Additionally, successful completion of catch allocation to river of origin, and enumeration of spawner escapement provide data to calculate total return by river system. Subsequently, total return estimates can be used to model spawner-recruit relationships, estimate optimum escapement, and forecast future run size.

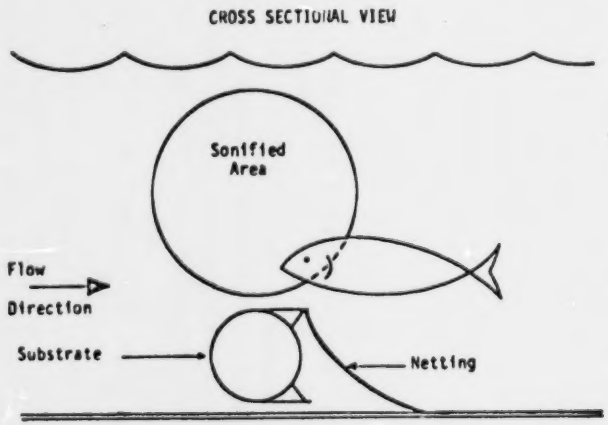
Since the early 1960's, the Alaska Department of Fish and Game has contracted with the Bendix Corporation to develop sonar equipment to count the number of sockeye salmon migrating to the spawning grounds in the major rivers of the Cook Inlet area. Glacial silt in these rivers severely limits less expensive visual means of escapement assessment. This development has resulted in the installation of Bendix side scanning sonar counters in four of the major sockeye salmon producing rivers in Upper Cook Inlet. Two units (one per bank) have been operated in each system since 1980. The purpose of this paper is to provide potential side scan sonar users with information relative to site characteristics which may help determine the appropriateness of this tool for use in their particular research and management situations.

METHODS

All sonar systems convert electrical energy into acoustical energy (sound waves) and provide information about underwater targets by measuring returning echoes. The side scan sonar system used in Upper Cook Inlet since 1980 consists of a single transducer, a 20 m tubular aluminum substrate, an electronic counter-printer, oscilloscope, batteries, solar charger panel, and necessary electric cable. The effective angles of detection are 2° and 4°. Pulse width of the transmitted sound is 100 microseconds, and the pulse repetition rate and signal strength are variable.

The substrate (Figure 1) is made up of three 5.6 m long sections with two 0.9 m couplers that slide together with a 0.5 m overlap forming a single unit. Offshore (target) and onshore (transducer housing) sections terminate the assembly ends. The substrate design includes two fairings





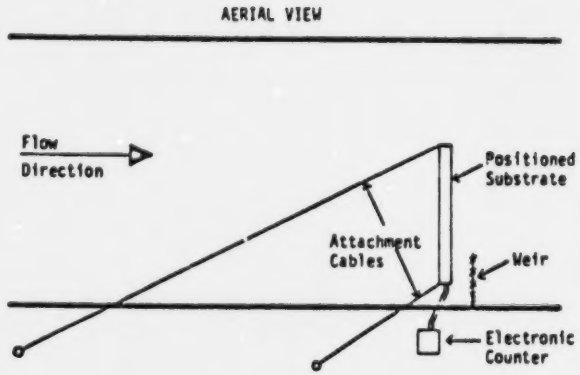


Figure 1. Side scan sonar system used to count salmon in Upper Cook Inlet, Alaska.

(vortex shedding fins) which provide stability in the current and aid in positioning the substrate relative to the bottom. The substrate rests on the stream bed perpendicular to the channel axis. Fish migrating upstream pass over the substrate and are hit by the transmitted sound waves. The counter-printer enumerates targets on the basis of returning echo strength and number of echoes returned. The counter-printer accumulates counts and hourly prints on tape counts for each of 12 linear substrate sectors. The tape printouts are removed from the counters, and the counts tabulated on a separate form once each day. The oscilloscope gives a picture of what is occurring in the sonified area (sonar beam). The accuracy of the counter is monitored by hand tallying fish-related echoes displayed on the oscilloscope. The ratio of visual (oscilloscope) counts to side scan sonar counts is used to derive a calibration factor and adjust the pulse repetition rate of the counter.

A more detailed description of the theory of operation of the side scan sonar counter, and a description of the electronic equipment are presented in Gaudet (1983). Procedures for deployment of the side scan sonar substrate and equipment operation are described in the 1980 Side Scan Fish Counter Installation and Operation Manual, Bendix Corporation (1980). Examples of data reporting are found in Tarbox et al (1983), and King and Tarbox (1983).

DISCUSSION

There are numerous factors to consider when choosing a site for deployment of a side scan sonar unit including bottom profile, current, substrate composition, and suspected fish movement patterns. Because each river has a unique combination of characteristics which are interrelated in terms of their applicability to sonar deployment, no one characteristic can be termed more important than the others.

Although the system was originally designed for the Kenai River in Upper Cook Inlet, our experience suggests that the "ideal" siting characteristics are almost never present, and one is faced with determining what effects these less than ideal characteristics might have on counting ability. Site selection is further complicated by the fact that river conditions generally change continuously, and the river may behave completely differently during low and high water conditions.

The following discussion of site characteristic parameters is based on experience gained by research biologists primarily on Upper Cook Inlet streams. Data used to derive siting parameters are for the most part sporadic in nature and should be viewed as general guidelines only. Each year as biologists throughout the state gain more experience in using the side scan sonar in their unique river conditions, new adaptations are developed which allow use of the units in many less than ideal situations.

Bottom Profile

The ideal bottom contour is a straight line dropping gradually which allows the substrate to lie flat on the bottom with approximately 0.3 m of water over the transducer (inshore end) and 2.1 m to 4.6 m of water over the target (offshore end).

If the bottom is concave, it will cause the substrate to bow and result in an area in the middle of the substrate which is below the sonified water cone. The result of this condition will be incomplete exposure of fish crossing the middle sectors to the broadcast sound waves, and insufficient returning echo strength to meet criteria necessary to count. Resultant distribution data are shown in Figure 2A. Attempts to lower the beam to alleviate this condition will cause reflections off the substrate in the outer sectors which are interpreted by the counter as targets and counted. In most cases, a concave bottom contour is caused by an immediate drop-off of the bank and gradual flattening of the bottom towards the middle of the river. This condition may be alleviated in some circumstances by excavating near shore to produce the desired contour.

A convex bottom contour generally results in a condition where the substrate tends to "flutter" in the current, resulting in a weak and fluctuating target. When this condition occurs, it becomes difficult to aim the beam properly. The substrate design includes two vortex shedding fins which allow the user to manually raise or lower the substrate by "aileroning" these fins into the current (Figure 1). Attempts to stabilize substrate flutter and improve returning echoes from the metal target (indicating accurate aiming) by aileroning the substrate slightly off the bottom may be effective, but only during periods of stable water level and velocity. If fish are crossing the substrate primarily over the inshore sectors, a weak or lost target may not be a problem. Proper aiming in this case can be insured by using an artificial target at intervals along the substrate.

The angle of the substrate relative to the water surface, and resultant depth may also affect counting ability. Ideally, the offshore end of the substrate should be between 2.1 m and 4.6 m below the surface (an angle of between 5° and 14°). A minimum depth of 1.2 m is required to provide 0.3 m for the substrate and approximately 0.6 m for the maximum beam width for the 2° beam at 20 m. This depth will not, however, keep the 4° beam from reflecting off the surface. Although returning echoes from this reflection may not count, they will cause interference on the oscilloscope image, inhibiting visual calibration of counter accuracy. If offshore depth is less than 1.2 m, surface reflection will count on an intermittent or regular basis depending on surface conditions. Offshore depths exceeding 4.6 m may result in fish aspects (position of the fish relative to the direction of the sonar beam) which return echoes of insufficient strength to qualify as appropriate targets. The degree of aspect change necessary for this to occur (i.e., angle of beam) has not been fully explored to date.

Substrate Composition

The ideal substrate should include above water characteristics which indicate permanence and stability, and below water substrate types not susceptible to significant bottom shifting (under normal operating conditions).

Initial inspection of potential sites should include some knowledge of previous short-term river course changes in addition to visual examination of the banks for evidence of historic course changes. Obvious signs such as age of vegetation (presence of older, large trees), can be supplemented by knowledge of climax and disturbed area vegetation. Visual signs such as active

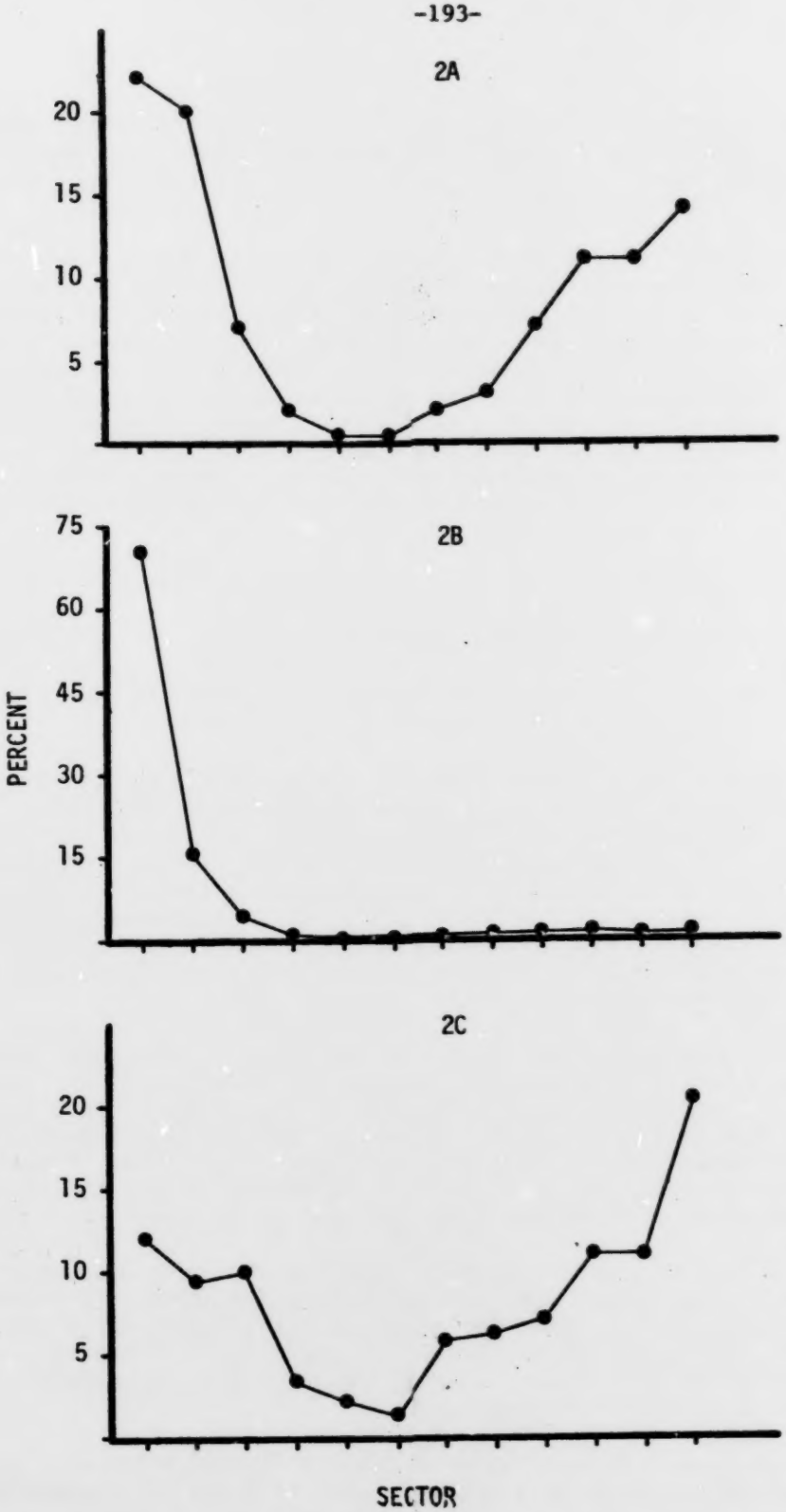


Figure 2. Distribution of sonar counts in 1.5 meter increments along the sonar counting substrate. 2A-Kasilof River north bank, 1982. 2B-Kasilof River north bank, 1983. 2C-Susitna River east bank, 1983.

bank sloughing or undercutting are also an indicator of active channel movement. Visual inspection should also determine the presence of shore line vegetation which may hang in the water. Aeration caused by such vegetation may cause false counts to occur in inner sectors.

Regardless of bottom substrate type, it should not be conducive to shifting under normal flow conditions. Placement of a substrate in a sand or mud bottom can result in the substrate "burying" itself, or creating changes in bottom profile or current on the downstream side. This may result in the formation of eddies and/or sand bars which change fish behavior and movement patterns. Substrates consisting of larger particles (gravel to rubble) appear to be acceptable with some limitations. Rocks which break the water surface will cause aeration which may, in turn, cause false counts. Additionally, rocks which are large enough to protrude above the upper surface of the substrate and are within close proximity to the substrate, may reflect sonar beam side lobes and alter counter accuracy.

Current

Ideally, the water velocity should be between 1.0 m and 2.1 m per second on the surface, and exceed 0.6 m per second near the bottom. In addition, current pattern should not be affected by eddies, whirlpools, or backwater areas. The site should also be above tidal influence.

The upper water velocity limit relates to the amount of stress the substrate can take during deployment. Problems associated with surface velocities above 2.1 m per second can be alleviated by sinking the substrate during deployment or by shortening the substrate length. Velocities in excess of 1.2 m to 1.5 m per second near the bottom will cause a downstream bow in a 20 m substrate which makes aiming difficult. If not aimed properly, the result may be areas along the substrate (generally where the bow is most pronounced) where fish can pass without fully entering the sonified beam. These fish may or may not count on a one-for-one basis.

Bottom velocities exceeding 0.6 m per second are generally adequate to force normally shore oriented species (sockeye and pink salmon) to travel well within the 20 m range of the side scan sonar. Data from counters operated in this current range generally indicate passage of greater than 90% of the migrating sockeye salmon within 7 m of the transducer (Figure 2B). Larger, less shore oriented species (chinook, chum, and coho salmon) have been less successfully counted under these conditions in Upper Cook Inlet.

The effects on fish behavior of operation of a side scan sonar in less than minimum current velocities are similar to those produced by operation in or near eddies, whirlpools, backwater areas, or areas within tidal influence. Generally, counter operation in minimal velocity conditions results in inconsistent fish speed, aspect when crossing the substrate, movement in the water column, and/or distribution from shore.

Inconsistent fish swimming speed affects counter accuracy, the logic of which is dependent on recording a minimum number of "hits" or consecutive returning echoes as a fish passes through the sonified area. Fish moving at variable speeds will be under- or overcounted, and the counter must be adjusted

to a pulse repetition rate which averages these under- and overcounts to provide an accurate estimate of escapement. Finding the correct pulse repetition rate will require an increased amount of time spent calibrating the counter by visual (oscilloscope) monitoring. A lack of adequate current velocity may also cause fish to cross the substrate at an angle different than 90°, thereby altering their aspect to the beam and changing returning echo strength. In extreme cases, these fish may be observed swimming directly toward or away from the transducer. Inconsistent movement in the water column may result from lack of adequate water velocity to force fish to follow the bottom where velocities are lowest. Counting accuracy will be affected by fish swimming completely over the sonified area or by fish only partly entering the beam. Finally, low water velocities may result in a distribution of fish from shore which exceeds the counting range (20 m) of the standard side scan sonar (Figure 2C), or fish may choose to move along the substrate rather than over it (particularly in shallow water conditions) and migrate upstream around the offshore end.

Fish Behavior

Several aspects of fish behavior have been observed in Cook Inlet which influence deployment site selection and success. In most cases the effects of these factors can only be guessed at prior to operation; however, they should be considered in the site-selection process. Location of the fall line of the river may influence migratory pathways, particularly in slower moving rivers. Additionally, the presence of multiple channels which may not be visible from the surface can distribute migrating fish. This is particularly true in large, glacial rivers. Success of enumeration may also be influenced by changes in fish behavior within each day or as the season progresses. Generaliy, these changes are a response to changes in river conditions, but they may also be related to fish density or simply diurnal changes. If these behavioral changes place fish outside the counting criteria of the system, then compensation by manipulation of calibration techniques and data may become necessary.

The site selection process should consider the possible existence of areas of the river (normally in close proximity to salt water) where stocks destined for other streams may mix with the stock to be enumerated. Placement of sonar gear can also be influenced by the presence of milling and/or spawning areas near a potential site. Unfortunately, these problems are not generally apparent prior to the decision-making process, and may take considerable effort to detect.

Finally, one should consider the density of fish over time, and river debris load, when determining whether the Bendix side scan sonar system is suitable for a proposed enumeration project. Since visual calibration of the system occurs for only a fraction of the operational time, the attending biologist must decide, when evaluating counter output, whether anomalous data are in fact fish. The difficulty of this decision is compounded in situations where high debris loads increase the possibility of false counts. The effect of these decisions on enumeration accuracy will vary depending on density of fish over time. That is, large runs of short duration offer less opportunity for calibration and data analysis errors of this type. Conversely, a protracted run of low density in a high debris load situation will force the biologist to make decisions which, on a relative basis, may have more influence on escapement estimate accuracy.

Obviously, the Bendix side scan sonar system is not perfect for estimating salmon escapement in every river system. It is by no means limited, however, to the "ideal" conditions previously described. Its effectiveness can and has been increased dramatically in less than ideal situations, with the degree of success greatly influenced by the ingenuity of the attending biologists. Familiarity with sonar theory and how river and fish behavior conditions affect counting ability are primary prerequisites for successfully adapting the system to each unique set of river conditions.

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AERIAL SURVEY ESTIMATES OF BRISTOL BAY SOCKEYE SALMON ESCAPEMENTS

by

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Aerial Survey Estimates of Bristol Bay Sockeye Salmon Escapements

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The annual escapements of sockeye salmon to most of the Bristol Bay lake systems have been enumerated by visual counts from towers on the trunk streams since the mid-1950s. The escapements and commercial catches are sampled to determine the age compositions and then combined to estimate the adult return from each brood year. Escapement-return statistics form the basis for management of the fisheries and are used as one method of forecasting runs. Aerial surveys of the spawning grounds in the Wood River and Kvichak lake systems have been conducted annually to examine the variability in the distribution of escapements within the lakes and to estimate the runs to individual lakes and spawning areas (Wood River). A comparison of the aerial survey estimates with the enumerated escapements for these lake systems provides an opportunity to measure the accuracy of aerial surveys and thus the accuracy that might be expected when only survey estimates are available (e.g., the Snake, Nushagak-Mulchatna and Branch systems in Bristol Bay).

The Wood River system contains four large lakes and two small lakes with a combined surface are of 425 km^2. The annual escapements since 1953 averaged 1 million and ranged from about 300,000 to nearly 3 million (Table 1). In contrast the escapements to the two large lakes in the Kvichak system (ca. 3,000 km^2) have averaged about 5 million since 1955 and ranged from 227,000 to 24 million. Aerial surveys of the beaches in Lake Clark (about 10% of the Kvichak Lake surface area) are hampered by glacial water, but the visibility in Lake Iliamna and the Wood River lakes is usually very good, e.g., Secchi depths are typically greater than 10 m during spawning surveys.

There are about 73 spawning areas (creeks, rivers and lake beaches) within the Wood River lake system which typically contain a significant number of spawners, i.e., more than a few hundred.[1] The surveys are timed to correspond to the timing of peak spawning, i.e., early-August for most small creeks, late-August to early-September for large rivers and mid-September for lake beaches (Gilbert 1968). Fourteen of the 25 creeks in the system are surveyed by foot because the number of spawners are difficult to count by air or they are more accurately counted by

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[1]Nelson, M. L. 1979. Spawning ground surveys in the Nushagak and Togiak Districts of Bristol Bay. Bristol Bay Data Report No. 73. Alaska Dept. Fish and Game.

Table 1. Statistics on sockeye salmon escapements, runs and returns to the Wood River lakes for the 1953-1983 brood years. (Number of fish in thousands).

Year	Escapement					Total	Catch	Run	μ (%)	Adult return	R/E
	4_2	5_3	5_2	6_3	Other						
1953	125	3	381	5	1	515	279	794	35	630	1.2
54	517	1	49	0	4	571	237	808	29	2267	4.0
55	1056	54	270	2	1	1383	704	2087	34	3681	2.7
56	529	29	208	7	0	773	725	1498	48	1078	1.4
57	122	2	153	10	2	289	281	570	49	375	1.3
58	785	18	129	1	27	960	648	1608	40	2342	2.4
59	1604	428	163	13	1	2209	1209	3418	35	1644	.7
60	404	380	207	24	1	1016	841	1857	45	2279	2.2
61	86	6	285	80	4	461	234	695	34	1173	2.5
62	806	11	54	1	2	874	1308	2182	60	1521	1.7
63	530	30	146	0	15	721	533	1254	43	1241	1.7
64	793	147	127	9	0	1076	1076	2152	50	970	.9
65	162	45	442	23	3	675	464	1139	41	1450	2.1
66	621	7	543	35	3	1209	751	1960	38	1640	1.4
67	305	47	155	7	2	516	530	1046	51	765	1.5
68	257	33	336	15	8	649	407	1056	39	730	1.1
69	263	185	133	16	7	604	452	1056	43	741	1.2
70	640	53	434	27	8	1162	596	1758	34	2595	2.2
71	364	30	361	90	6	851	587	1438	41	1163	1.4
72	300	32	78	20	1	431	155	586	26	1336	3.1
73	35	4	254	33	5	331	71	402	18	1415	4.3
74	1205	155	330	14	5	1709	359	2068	17	4927	2.9
75	344	148	684	69	25	1270	303	1573	19	4431	3.5
76	448	97	249	15	8	817	645	1462	44	5182	6.3
77[1]	163	24	343	29	3	562	250	812	31	3161	5.6
78	1689	16	506	14	42	2267	1865	4132	45	(3110)	(1.4)
79	727	181	778	15	5	1706	1814	3520	52		
80	1438	298	1178	30	25	2969	1469	4438	33		
81	306	152	573	201	1	1233	3132	4365	72		
82	401	18	487	57	13	976	2640	3617	73		
83	998	164	196	2	1	1361	3140	4501	70		

[1]1977-83 preliminary data from Alaska Dept. Fish and Game.

ground surveys. For analytical purposes, some of the 41 beach spawning areas were combined and annual counts for 30 beach areas, 25 creeks and 7 interconnecting rivers were examined.

The annual spawning ground estimates for the individual major creeks (average of 3,000+) and beaches (average of 7,000+) and all rivers in the Wood River system were generally poorly correlated with the lake system escapements (Table 2). Most of the correlation was caused by a correspondence with the very large and very small escapement. The combined estimates by type of spawning ground were also rather poorly correlated with the escapement (.67 for beaches to .72 for creeks); however, the combined annual survey estimates corresponded quite closely with the escapements with the exception of observations from 1955, 1980 and 1983 (Fig. 1). After 1957, when nearly all important areas were surveyed, the annual estimates accounted for an average of 49% of the escapements, but the surveys tended to account for a smaller proportion of the large escapements than the small escapements (Table 3). When only the six largest (most abundant) spawning areas were used the trend in the escapements since 1953 was still evident, although the correlation was somewhat less than when all areas were used. A similar result was obtained when only 8 creeks (those with ground counts, Table 2) were used as an index of the escapement (Fig. 1).

The aerial surveys of the Kvichak system have been less consistent in coverage than those in the Wood River system and an average of only 18% of the escapements were accounted for by the surveys (Table 4). However, the annual fluctuations in the escapements were much greater and the correlation between the aerial estimates and the enumerated escapements was higher ($r = .95$) than in the Wood River system. Excluding years in which the escapement was 8 million or more, the correlation between the escapements and the survey estimates was still quite high ($r = .94$). The 1980 surveys of the beaches were hampered by high water and poor visibility. The other peak-year survey estimates were well correlated with the escapements.

Little Togiak Lake (6 km^2) in the Wood River system provides a contrast to the survey conditions in the Kvichak, and the larger Wood River lakes. About 75% of the spawning is on one beach in this small lake. The escapements were enumerated for 9 years and compared to the aerial counts and the aerial estimate of the escapement (expanded counts from the ratio of total aerial estimates to total escapement). The aerial estimates of the escapement were quite good except in 1982 (Table 5). In that year the survey indicated a small escapement when there was actually an average escapement. A change to a relatively inexperienced observer after 1979 may have been partly responsible for the large error in 1982 but more important is that the aerial estimate of the escapement depends on essentially one estimate for one beach. When estimates from several spawning grounds are combined, as is the case for most large lakes, the estimated escapement is likely to be more accurate.

Table 2. Means and standard deviations of annual spawning ground estimates and the correlations with the annual lake system escapements to the Wood River lakes, 1953-83.

Spawning ground	Number of spawners (1,000's) Mean	S.D.	Range	Correlation with lake system (r)
Rivers (aerial)				
Agulowak	111	75	10, 313	.64
Agulukpak	85	57	9, 250	.44
Wood	11	13	1, 50	.65
Grant	10	9	1, 32	.54
Little Togiak	8	6	1, 21	.66
Peace	6	6	0, 18	.46
Wind	1	1	+, 5	.49
Beaches (aerial)				
Kulik	28	29	+, 111	.73
Silver Horn	27	25	1, 79	.35
Hardluck	20	16	1, 56	.65
Anvil Bay	18	13	1, 51	.60
Little Togiak	10	6	4, 25	.37
Lynx	10	10	2, 41	.57
B9-B12	8	9	0, 30	.48
Mikchalk	8	8	+, 27	.38
N4-N6	8	4	2, 18	.51
Allah	7	7	1, 29	.36
Creeks (aerial)				
Stovall	7	14	+, 75	.35
Kema	5	5	1, 20	.43
Pike	4	4	+, 16	.42
Moose	4	5	+, 16	.65
Hope	3	4	+, 15	.67
Creeks (ground)				
Pick	12	14	2, 78	.64
Ice	8	5	2, 25	.42
Bear	4	2	1, 10	.70
Hansen	4	4	+, 16	.50
Fenno	3	4	+, 17	.63
Lynx	3	4	+, 17	.79
Happy	3	2	+, 7	.42
Hidden	3	3	+, 16	.56

+ = less than 1,000.

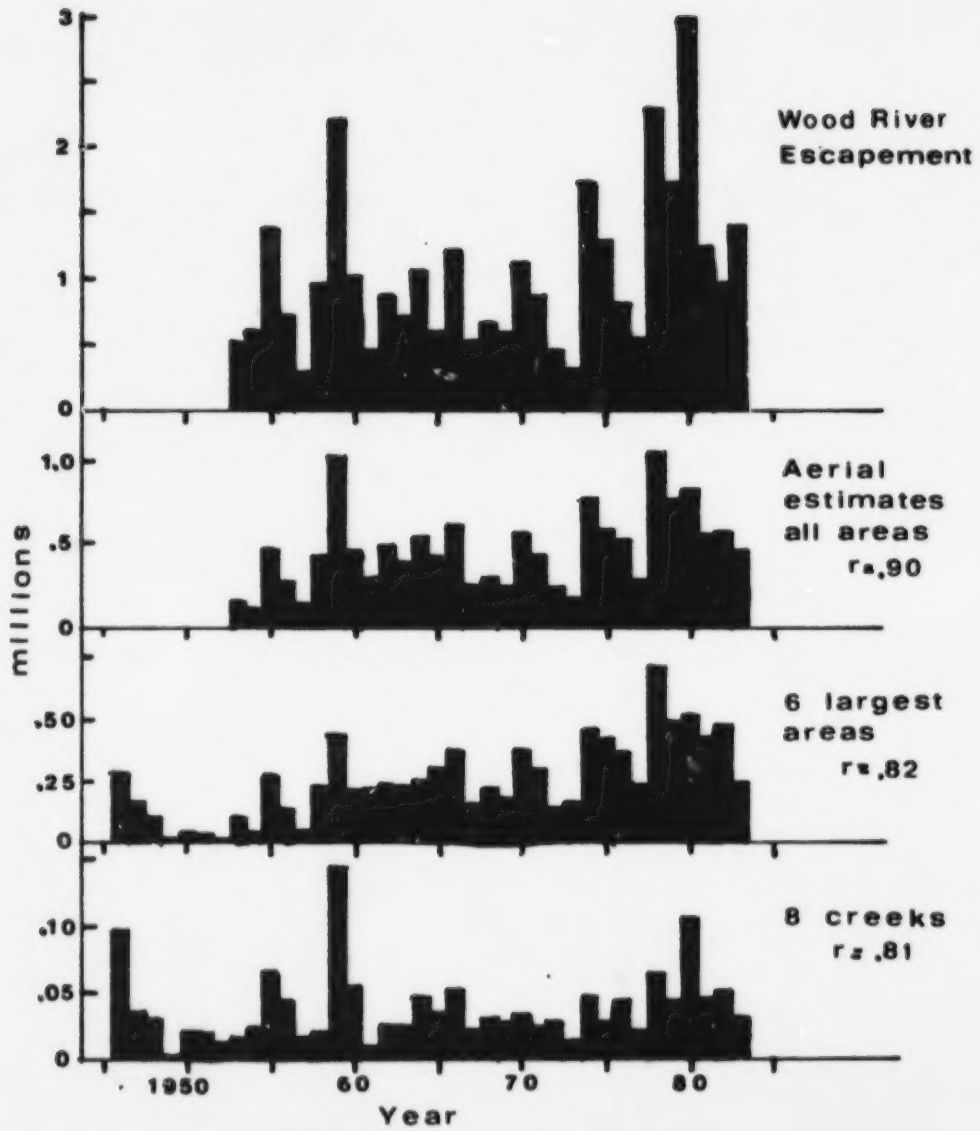

Fig. 1. Comparison of the annual escapements of sockeye salmon to the Wood River lakes (from tower enumeration) with aerial estimates of all spawning grounds, the six largest (most abundant) areas and eight creeks for which ground survey counts were made annually.

Table 3. Annual aerial survey estimates of sockeye salmon spawners in the Wood River lakes and the percent of the enumerated escapement.

Year	Number of areas surveyed	Aerial survey estimates (1,000's)				Percent of total escapement
		Rivers	Creeks	Beaches	Total	
1953	30	104	32	16	152	30
54	35	26	34	62	122	21
55	44	235	139	119	493	36
56	52	119	83	71	273	35
57	57	73	26	38	137	47
58	58	70	41	325	436	45
59	60	278	305	444	1027	46
60	60	131	98	244	473	47
61	60	207	23	62	293	64
62	62*	127	73	282	482	55
63	62	118	40	241	399	55
64	62	146	100	290	536	50
65	62	284	49	103	435	64
66	62	287	96	225	608	50
67	62	105	27	119	251	49
68	62	170	29	81	280	43
69	62	181	30	44	255	42
70	62	330	49	180	558	48
71	62	203	42	175	420	49
72	62	118	27	66	212	49
73	62	157	12	25	194	59
74	62	285	88	397	770	45
75	62	426	54	106	586	46
76	62	322	60	143	525	64
77	62	210	21	63	294	52
78	62	539	114	400	1053	46
79	62	408	54	311	773	45
80	62	481	142	178	801	27
81	62	451	54	53	558	45
82	62	443	58	67	568	58
83	62	169	62	219	450	33

*7 rivers, 25 creeks and 30 beaches.

Table 4. Aerial survey estimates and the annual escapements of sockeye salmon to the Kvichak lake system.

Year	Number of areas surveyed	Aerial estimates of spawners (1,000's) Streams & ponds	Mainland beaches	Island beaches	Total	Total system escapement	Percent of total escape.
1955	35	29	4	-	33	251	13
56	36	1,023	265	43	1,331	9,443	14
57	52	269	80	5	354	2,843	12
58	43	68	27	4	99	535	19
59	47	100	11	18	128	680	19
60	45	1,362	489	1,000	2,851	14,630	19
61	44	395	152	107	654	3,706	18
62	64	230	46	10	286	2,581	11
63	64	39	8	5	52	339	15
64	72	73	7	15	95	957	10
65	78	1,333	387	1,958	3,678	24,326	15
66	75	436	134	49	619	3,776	16
67	73	366	150	19	535	3,216	17
68	89	224	36	77	337	2,557	13
69	96	434	114	132	680	8,394	8
70	86	1,441	546	643	2,630	13,935	19
71	65	324	51	61	436	2,387	18
72	83	149	27	10	186	1,010	18
73	93	58	10	7	75	227	33
74	96	635	121	140	896	4,433	20
75	113	1,671	423	557	2,651	13,140	20
76	not analyzed					1,965	
77	" "					1,341	
78	80	696	176	6	878	4,149	21
79	86	2,072	681	101	2,854	11,218	25
80	56	1,631	135	205	1,971	22,505*	9
81	75	285	28	23	336	1,754	19
82	83	368	40	11	419	1,135	37

*An estimated 5 million fish died at a river blockage before reaching spawning grounds, thus actual escapement to spawning area was 17,505.

Table 5. Comparison of sockeye salmon escapement estimates for Little Togiak Lake made from aerial surveys and tower enumeration.

Year	Aerial estimates: Aerial counts	Aerial estimates: Expanded (escapement)	Visual enumeration escapement	Aerial-visual estimates	% error	Aerial observer
1961	7,700	11,000	10,500	+ 500	+ 4.8	A
1975	6,100	23,800	30,000	- 6,200	-20.7	B
1976	9,500	17,300	18,000	- 700	- 3.9	B
1977	7,700	26,400	26,000	+ 400	+ 1.5	B
1978	12,500	36,200	45,000	- 8,800	-19.6	B
1979	16,900	53,600	44,000	+ 9,600	+21.8	B
1980	15,500	65,000	81,000	-16,000	-19.8	C
1981	15,300	74,000	60,000	+14,000	+23.3	C
1982	5,400	13,000	36,000	-23,000	-63.9	C
Means	10,733	35,589	38,944	- 3,356	- 8.5	
Absolute mean				8,800	19.9	

Indexing annual escapements to a large system may provide poor estimates unless the more abundant spawning populations are included in the surveys. Moreover, one lake or one type of spawning ground within a system may not be representative of the entire lake system. In the Wood River system the trends in the escapements and estimated runs have been significantly different for the individual lakes and types of spawning ground (Fig. 2). However, when the surveys are relatively complete then the information they provide can be very useful to the management of the annual runs to the system. For example, escapement goals for the Wood River system have been established on the basis of escapement-return statistics for the individual lakes and type of spawning area. The river spawners tend to spend 3 years at sea (ages 5_2 and 6_3), whereas the beach spawners usually spend 2 years at sea (ages 4_2 and 5_3). The escapement goal for an annual run can be adjusted in-season based on the age composition in the early part of the run.

Acknowledgments

The aerial surveys in the Wood River system were conducted by Messrs. J. R. Gilbert (1953-58), W. A. Church (1959-61), M. L. Nelson (1962-79) and W. A. Bucher (1980-83); and the surveys in the Kvichak system were done by H. D. Smith (1955-60), O. E. Kerns (1961-66) and P. H. Poe (1967-82).

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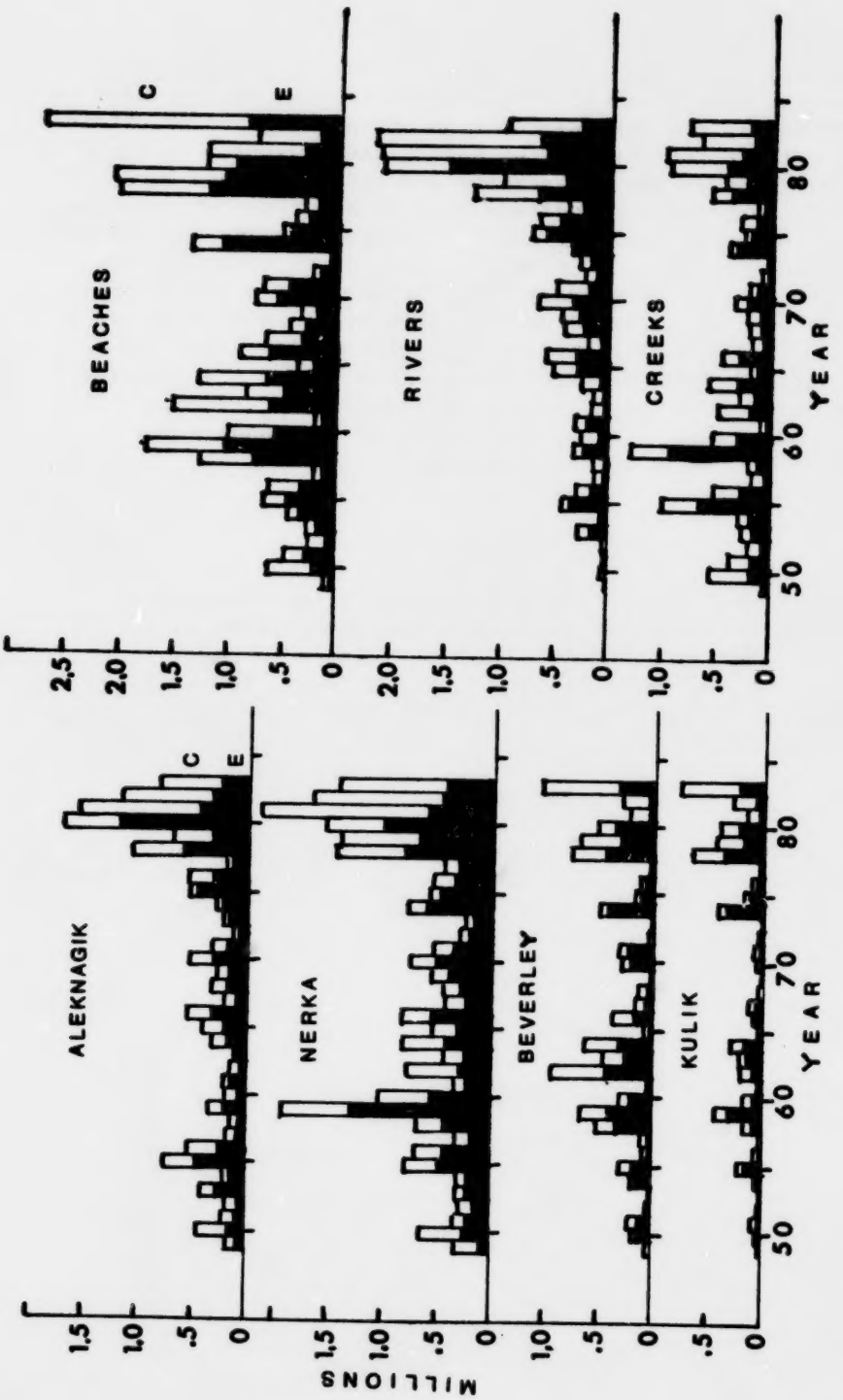

Fig. 2. Estimates of the annual runs, catch (C) plus escapement (E), to the major Wood River lakes and by type of spawning area.

THE ACCURACY OF MARK-RECAPTURE ESTIMATES OF ESCAPEMENTS

by

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INTRODUCTION

Tagging or marking has been used to enumerate Pacific salmon escapements since at least 1938 (Howard 1948). Cousens et al. (1982) and Eames et al. (1981) have reviewed the theoretical development and use of this technique. Although refinements to the equations exist (Ricker 1975), the principle is simple: if a sample (M) is marked in a closed population of size N and a number R of these marks are recovered in a subsequent sample of size C, then the proportion of marks recovered will approximate the proportion of all marks in the population, i.e. $R/C \approx M/N$. And, therefore, the estimate of N is: $\hat{N} = MC/R$.

The theory assumes that a marked individual is just as likely to be found in the recovery sampling as an un-marked individual. That is, it assumes that marked fish survive as well and are just as catchable as un-marked fish, that marks or tags are not lost and are always recognized, and that the population is indeed a closed one. Junge (1963) showed that, theoretically, the tagging and recovery sampling can be selective if the sources of selectivity are independent of each other but the recovery sample must always be non-selective with respect to mark status. It is on the above conditions that equations have been developed to obtain confidence intervals for mark-recapture estimates (e.g. Eames et al. 1981).

But these conditions have never been met in estimating salmon escapements. This is generally realized and the realization led some workers to check the accuracy of the technique by comparing mark-recapture estimates with weir counts. In fact, these checks have been more frequent than one would think since most have not been published or have appeared in local, limited-access publications. Perhaps this is because the error in the method is expected to vary greatly between situations. Analysing these evaluations together, however, will test this expectation and perhaps provide some insight into the technique's utility and what can be done to improve it. That is the intent of this paper. The review is mostly confined to British Columbia, my area of familiarity, and I have purposely avoided duplicating the reviews by Eames et al. (1981) and Cousens et al. (1982).

RESULTS AND DISCUSSION

The evaluation tests are summarized in Table 1. Some authors of the tests in Table 1 obtained their estimates using slightly different data than I was able to obtain or they used it differently. For example, Vernon, Hourston and Holland (1964) and several others calculated male and female populations separately and added the results to get a total. Consequently, the $\hat{N}$ figures

Table 1. Mark-recapture estimates ($\hat{N}$) of enumerated salmon escapements.

Location (and citations)[a]	Year	Fence Count (N)	Tagging: Proportional	Tagging: Adjacent[b]	Tagging: No. tagged (M)[c]	No. dead examined (C)[d]	C includes dead on fence	No. recovered (R)	$\hat{N}$ (MC/R)[e]	% error[f]	Comments
						Sockeye					
Cultus L. (1)	1938	13,342	N	(N)	4,416 (33.1)	4,735 (35.5)	Y	1,519	13,765	+ 3.2	
						4,174 (31.3)	N	1,315	14,017	+ 5.1	(g)
	1939	73,189	Y	(N)	3,660 (5.0)	9,832 (13.4)	Y	477	75,441	+ 3.1	
						8,504 (11.6)	N	370	84,121	+ 14.9	(g)
Lakelse system (2)	1952	17,726	Y	N	953 (5.4)	5,179 (29.2)	N	122	40,456	+128.2	(h)
	1953	11,827	Y	N	329 (2.8)	8,671 (73.3)	N	216	13,207	+ 11.7	(h)
	1954	8,473	Y	N	357 (4.2)	7,206 (85.0)	N	211	12,192	+ 43.9	(h),(i)
Williams Cr. (2),(3),(4)	1939	23,918	N	Y	2,000 (8.4)	5,715 (23.9)	Y	347	32,939	+ 37.7	
						1,468 (6.1)	N	60	46,933	+ 96.2	
	1953	7,812		Y	444 (5.7)	986 (12.6)	Y	51	8,584	+ 9.9	(j)
						265 (3.4)	N	15	7,844	+ 0.4	(j)

Table 1 (cont'd)

Location (and citations)[a]	Year	Fence Count (N)	Tagging: Proportional	Tagging: Adjacent[b]	Tagging: No. tagged (M)[c]	No. dead examined (C)[d]	C includes dead on fence	No. recovered (R)	$\hat{N}$ (MC/R)[e]	% error[f]	Comments
						Sockeye					
Williams Cr. (2), (3), (4)	1954	6,390		Y	330 (5.2)	1,251 (19.6)	Y	58	7,118	+ 11.4	(j)
						102 (1.6)	N	5	6,732	+ 5.3	(j)
Scully (Schulbuckhand) Cr (2)	1951	1,214	Y	Y	237 (19.5)	419 (34.5)	Y?	54	1,839	+ 51.5	
Babine L. system (5) to (10)	1946	<451,599	Y	(N)	8,411 (2.0)	49,804 (>11.0)	Y	517	810,254	>+ 79.4	(k)
	1947	~492,561	Y	(N)	~ 4,275 (~0.8)	~113,100 (~23)	Y?	803	728,000	+ 22	(k),(l)
	1958	842,812	Y	(N)	7,870 (0.9)	129,495 (15.4)	Y?	610	1,670,698	+ 98.2	(l)
	1962	548,000	Y	(N)	6,200 (1.1)	~164,200 (~30)	Y?	1,548	~ 657,600	+ 20	(l)
						Pinks					
Keogh R. (11),(12)	1959	25,721	N	Y	1,182 (5.4)	3,732 (14.5)	N	64	68,820	+ 167.6	(m)
Glendale (Tom Browne) R. (11),(12)	1961	164,127	N	N	1,053 (0.6)	51,732 (31.5)	Y	234	232,248	+ 41.5	(n),(o)
						49,459 (30.1)	N	220	236,632	+ 44.2	(n),(o)

Table 1 (cont'd)

Location (and citations)[a]	Year	Fence Count (N)	Tagging: Proportional	Tagging: Adjacent[b]	Tagging: No. tagged (M)[c]	No. dead examined (C)[d]	C includes dead on fence	No. recovered (R)	$\hat{N}$ (MC/R)[e]	% error[f]	Comments
						Pinks					
Glendale (Tom Browne)R. (11), (12)	1961	164,127	N	Y	1,856 (1.1)	51,732 (31.5)	Y	446	220,294	+ 34.2	(n),(p)
						49,459 (30.1)	N	408	228,546	+ 39.2	
			Y	Y	7,922 (4.8)	51,732 (31.5)	Y	2,129	192,138	+ 17.1	(n),(q)
						49,459 (30.1)	N	1,934	202,802	+ 23.6	
Lakelse R. (13),(14),(15)	1960	111,936	Y	Y	3,332 (3.0)	22,435 (20.0)	Y	472	158,376	+ 41.5	
						19,320 (17.3)	N	349	184,453	+ 64.8	
	1961	305,675	Y	Y	6,043 (2.0)	39,348 (12.9)	Y	614	387,264	+ 26.7	
	1962	625,000	Y	Y	6,429 (3.0)	64,505 (10.3)	Y	509	814,740	+ 30.4	
						Coho					
Big Beef Cr. (16)	1980	1,613	Y	Y	402 (24.9)	102 (6.3)	Y	27	1,482	- 8.1	
						75 (4.6)	N	21	1,801	+ 11.6	
Minter Cr. (17)	1952	1,503		Y	89 (5.9)	175 (11.6)	Y?	10	1,557	+ 3.6	
					278 (18.5)	175 (11.6)	Y?	32	1,520	+ 1.1	(r)

Table 1 (cont'd)

Location (and citations)[a]	Year	Fence Count (N)	Tagging: Proportional	Tagging: Adjacent[b]	Tagging: No. tagged (M)[c]	No. dead examined (C)[d]	C includes dead on fence	No. recovered (R)	$\hat{N}$ (MC/R)[e]	% error[f]	Comments
					Coho						
Minter Cr. (18)	1954	715			559 (78.2)	26 (3.6)	Y?	18	807	+ 12.9	(r)
					Chum						
Minter Cr. (17, 19, 20)	1952	1,107		Y	142 (12.8)	571 (51.6)	Y?	70	1,158	+ 4.6	
	1953	1,048		Y	77 (7.3)	149 (14.2)	Y?	10	1,147	+ 9.4	
	1954	1,132		Y	101 (8.9)	378 (33.4)	Y?	34	1,123	- 0.8	

Footnotes to Table 1.

[a]Data were obtained from the following sources. When I had access to the raw data, I sometimes interpreted these data differently than the original author.

(1) Howard 1948
(2) M. P. Shepard, unpublished data in Pacific Biological Station salmon archives (subsequently referred to as "PBS Archives")
(3) Pritchard and Cameron 1940
(4) Pritchard 1947a
(5) Brett 1946
(6) Brett 1952
(7) Pritchard 1947b
(8) Pritchard and Withler 1947
(9) McDonald 1959
(10) Smith and Jordan 1963
(11) Vernon, Hourston, and Holland 1964
(12) Anon., unpublished data in PBS Archives
(13) H. D. Smith, unpublished data
(14) Smith et al. 1963

Footnotes to Table 1.

[a]Data were obtained from the following sources (cont'd)
(15) Smith 1962
(16) Eames and Hino 1981
(17) Salo and Noble 1953(?)
(18) Noble 1955a(?)
(19) Salo and Noble 1954(?)
(20) Noble 1955b(?)

[b]"Y" (yes) means that ripe fish were tagged on or immediately below the spawning grounds. "N" (no) means that the salmon were tagged some distance away and, usually, some weeks before spawning, e.g., tagging sockeye as they enter a lake, where they mature for a few weeks before spawning. "(N)" was used when some of the sockeye referred to in the above example eventually spawned above the fence in the outlet.

[c]The figure in parentheses is the percent tagged at the fence (= 100 M/N).

[d]The figure in parentheses is the percentage of the fence count which was later examined for tags (= 100 C/N).

[e]$\hat{N}$ occasionally does not equal MC/R as shown in this table (see text).

[f]Defined as 100 $(\hat{N} - N)/N$.

[g]Does not include data from the outlet above the fence.

[h]Tagging was done at a fence which was a few hundred yards downstream from Lakelse Lake. Tags were noted about 55 days later as the sockeye passed fences on the two main spawning grounds, Williams and Scully Creeks, which flow into Lakelse Lake. About 98% of the run spawns in these two creeks.

Footnotes (cont'd)

[i]N includes an estimate of 866 sockeye that were not counted.

[j]The numbers of tagged sockeye released into the stream include 197 sockeye in 1953 and 195 sockeye in 1954 that were already tagged. They had been tagged in the outlet to Lakelse Lake about two months earlier (see [h] above).

[k]The reported catch in Babine L. by native fishermen (more than 24,106 in 1946 and about 30,000 in 1947) was subtracted from the fence count and the tags recovered from this fishery (1,054 in 1946 and 950 in 1947) were subtracted from the applied tags (see text). The percentages in the M and C columns are relative to the uncorrected and corrected fence counts, respectively.

[l]It is not known whether C includes dead on the fence but, in any event, most spawning occurs elsewhere.

[m]Excludes data from 220 pinks of unknown sex that were tagged with un-numbered tags at the start of the run.

[n]N includes an estimate of 5,000 pinks that were not counted.

[o]Pinks were obtained for tagging by seining off the mouth, in Glendale Cove.

[p]Pinks were obtained for tagging by beach-seining in the stream below the fence.

[q]Pinks were tagged from the fence pens.

[r]Using marked coho that were counted through the fence. They had been marked as juveniles.

in Table 1 do not always equal the $\hat{N}$ derived from using the Table's M, C and R data. In some cases, when the data were available, I calculated mark-recapture estimates which differ from the author's result. The simple $\hat{N} = MC/R$ formula was used throughout because that is the formula most authors used and refinements to the basic equation usually make little difference to the result.

INTERPRETING THE RESULTS

1. Fence effects

It is important to realize that the mark-recapture estimates in these tests will usually be more accurate than they would have been had there been no fence. The fence allows one to tag a constant proportion of the run each day and to tag the sex and size groups non-selectively. Furthermore, a fence prevents downstream emigration of spawners, living and dead. This latter effect is particularly important because it is a common (but not universal) observation that the mean distance that tagged salmon migrate above the fence is less than the mean for untagged salmon and that tag ratios in carcass samples are often highest on the fence grates and immediately above the fence (e.g. Howard 1948; Schaefer 1951; Salo and Noble 1954 (?); Noble 1955(?); Vernon et al. 1964; H. D. Smith unpublished data; and M. P. Shepard unpublished data). There is also a suspicion that tagged fish are more likely to emigrate out of the stream (Vernon et al. 1964).

I have attempted to make the results more comparable to the general situation in which there is no fence by excluding dead-on-fence examinations and tag recoveries whenever possible (Table 1). I had the necessary data from ten tests. The excluded data had larger than average tag ratios in eight of these ten tests: excluding the data increased the mark-recapture estimates in the eight tests. Shepard's experiments at Williams Creek (1953 and 1954) were the two exceptions. Both gave reduced estimates when the dead-on-fence data were removed (M. P. Shepard unpublished data). The effect on the relative errors is summarized in Table 2.

2. Population estimates of sockeye in the Babine Lake system in 1946 and 1947

Pritchard (1947b) and Pritchard and Withler (1947) reported on the comparisons made at Babine Lake in 1946 and 1947 (Table 1). They noted that the native fishery for sockeye was taking a disproportionate number of tagged fish. They speculated that this was probably because (1) the Peterson tag increased the vulnerability of tagged salmon to gillnets, (2) tagged fish were probably being chosen by gaff fishermen (a reward was offered for recovered tags), and (3) the 1946 catch by the native fishery was probably under-estimated, thereby increasing the tag ratio (R/C). The effect of the native fishery was partially removed in the analyses for these two years by subtracting the catch from the fence count and reducing the number of available tags (M) by the number of tags recovered in the fishery. However, since the catch was probably under-estimated in 1946 more than the tag returns from the catch were under-estimated, the true error of the estimate may be more than +79.4% shown in Table 1.

Table 2. The effect of removing dead-on-fence data on the accuracy of mark-recapture estimates.

Species	Location	Year	% Error	
			Includes dead on fence	Excludes dead on fence
Sockeye	Cultus L.	1938	+ 3.2	+ 5.1
		1939	+ 3.1	+14.9
	Williams Cr.	1939	+37.7	+96.2
		1953	+ 9.9	+ 0.4
		1954	+11.4	+ 5.3
Pinks	Glendale R.	1961	+41.5	+44.2
			+34.2	+39.2
			+17.1	+23.6
	Lakelse R.	1960	+41.5	+64.8
Coho	Big Beef Cr.	1980	- 8.1	+11.6
Mean			19.2	30.5
S.E.			5.75	9.77

TESTS WITH COMPLETE TAG RECOVERIES

Shepard (unpublished data) and Vernon et al. (1964) tagged salmon before they reached fences and tagged more as they passed these fences. This allows one to determine the loss of tags (due to shedding of tags, tagging mortality or increased emigration of tagged salmon from the stream).

Shepard tagged sockeye in Lakelse River before they entered Lakelse Lake. The salmon matured in the lake for about 55 days before almost all the remaining population entered Williams and Scully creeks to spawn. He regularly surveyed the lake for carcasses and he had fences operating on both creeks. Virtually all the sockeye entering the creeks were examined for tags in 1953 and 1954. In 1952, only a part of the Williams Creek run passed through the fence because some sockeye were able to ascend an un-fenced side channel.

Twenty-nine percent of the 1952 population which originally entered the lake was subsequently checked at the creek fences. The number of recovered tags gave an estimate which was over twice the original population size. About 73% were left by the time the 1953 population reached the creeks and the mark-recapture estimate from the tags that were seen at the fences was 12% too high. In 1954, 85% reached the creeks and the mark-recapture estimate was 44% too large.

The extent of tagging mortality is suggested by the percentage of tagged carcasses in the lake. The tag ratios (in percent) were:

	Lakelse R. fence	Dead in the lake	Creeks
1952	5.4	13.2	2.4
1953	2.8	2.6	2.5
1954	4.2	18.2	2.9

If lake and creek recoveries are combined, the errors in the estimates for 1952, 1953 and 1954 are +104%, +12%, and +41%, respectively. Shepard noted that there were inadequate passage facilities at the Lakelse River fence in 1952 and this caused damage to fish. The lake was unusually warm in 1954. However, 85% of the 1954 run into the lake eventually passed the creek fences, compared to 73% of the run in 1953, when there was no evidence of substantial tag mortality.

Vernon et al. (1964) tagged pinks in the cove off the mouth of Glendale River, in the river below the fence, and from the fence itself. The resulting estimates were 44.2%, 39.2%, and 23.6% too large, respectively, based on carcass recoveries on the spawning grounds (Anon. unpublished data in PBS Archives) (Table 1). Only 61.5% (1,141) of the stream tags were counted through the fence. Surprisingly, 749 cove tags were examined at the fence, which is 71.1% of the original number and relatively more than the stream-tagged salmon (unpublished data, PBS Archives).

Tagging was done as the run into the river progressed and yet 38.5% of the stream tags and 28.9% of the cove tags were lost. If the numbers of stream- and cove- tagged pinks that are known to have passed the fence are used to calculate $\hat{N}$ from the spawning ground and dead-on-fence samples, the estimation errors are reduced to -6% and +6%, respectively (Vernon et al. 1964).

Salo and Noble 1953(?) did not achieve a total recovery but their results can also be used to assess tagging mortality and tag loss. They disc-tagged 89 of the 1,503 coho which passed the Minter Cr. fence in 1952 and obtained an estimate which was only 3.6% larger than 1,503. However, another 278 of the coho that passed the fence had been fin-clipped as juveniles. Using recoveries of these fish, the estimate was even better, only 1.1% too large. Assuming the marks were recognized as well as the tags, the marked fish can be considered controls. The difference in the errors from tagging and marking was only 2.5% but, of course, there was little room for improvement. Considering also that there were about three times more marks than tags, the conclusion must be that there was little tagging effect in this test.

VARIATION IN ERRORS OF MARK-RECAPTURE ESTIMATES

It is evident from Table 1 that there is a large variation in estimation errors. The sockeye census by Shepard in the Lakelse Lake system was replicated for three successive years, the only apparent difference in method being the use of different tagging ratios. Mark-recapture over-estimated the 1952, 1953 and 1954 runs by 128, 12 and 44 percent, respectively. These errors were inversely correlated with the tagging ratios: 5.4, 2.8, and 4.2 percent, respectively.

There are four years of comparisons at Babine Lake. As already discussed, the data analysis is not identical in each year and there were some differences in methods. For example, operculum tags were used in 1958 instead of Petersen tags (McDonald 1959). However, it seems unlikely that these are the main causes of such a large range in errors: from +20% to +98%.

Both the Lakelse Lake and Babine Lake tests entailed tagging sockeye several weeks before the recovery sampling. The tagging of Lakelse River pinks was adjacent to the spawning grounds and was done as the pinks occupied the spawning grounds to spawn (H. D. Smith unpubl. data, Smith 1962 and Smith et al. 1963). The variation was less in this situation. In 1960, 1961 and 1962 the method over-estimated escapements by 42%, 27% and 30%, respectively. The unweighted mean error was 33% (S.E.=4.45%).

Salo and Noble (1953, 1954) and Noble (1955) obtained estimates of chum spawners in Minter Creek from 1952 to 1954. The estimates were also less variable: +4.6%, +9.4% and -0.8%, respectively (Table 1).

Overall, the mark-recapture tests over-estimated sockeye from 0.4% to 128.2%. For pinks, the range was 17.1% to 167.6% and for chum it was -0.8% to +9.4%. Depending partly on how the data were analysed, coho estimates ranged from -8.1% to +11.6%.

The tests were done in different ways, under different conditions and using different species. The large variation in errors, even within replicate tests, indicates that mark-recapture experiments should be designed to collect data which will help assess tag loss, tagging mortality, un-even recovery sampling and so on. One prerequisite is to tag throughout the run and, in particular, to have a continuous and uniform recovery effort over the entire spawning area (Howard 1948, Schaefer 1951). The census by Eames and Hino (1981) is a recent example of a well designed experiment.

GENERAL MAGNITUDE OF THE ERRORS

The large variation in errors also means that a statistical summary of the errors has limited application. Still, it is useful to have a general summary of the size of the errors involved, as diverse as they may be. I log-transformed the errors because the distributions are markedly skewed to the right. Secondly, I used estimates which excluded dead-on-fence data whenever there was a choice between estimates in a test. The results are shown in Table 3.

Table 3. Summary of the relative errors of the estimates.

Species	No. Tests	Geometric mean (%)	95% Confidence Limits	
			Lower (%)	Upper (%)
Sockeye	13	21.3	8.0	56.3
Pink	7	44.8	24.0	83.5
Coho[a]	2	6.5		
Chum[b]	3	4.4	-8.3	17.1
All species[c]	25	17.5	5.4	57.0

[a]Excludes the Minter Creek tests that used juvenile-marked adults.

[b]Arithmetic mean (one error was a negative number, hence its log is not a real number).

[c]Derived by assigning a value of 0.1% to the negative error of -0.8% from the 1954 chum study at Minter Creek.

The mean errors shown above should be regarded as minimum estimates. The summary includes tests whose data included dead-on-fence recoveries. In other tests, the estimates increased an average of 11% when dead-on-fence data were excluded (Table 2). I applied this further 11% error to the tests where the fence was adjacent to most of the spawning grounds and where dead-on-fence data were included in the recoveries: Scully Creek sockeye in 1951, Lakelse River pinks in 1962 and 1963 and the coho and chum estimates from Minter Creek. The geometric mean errors then became 21.6% for sockeye, 49.1% for pinks, 13.0% for coho, 14.8% for chum, and 24.9% overall.

The errors shown in Table 1 and their summary are still minimum estimates of the errors to be expected in a mark-recapture census where there is no fence. A fence allows tagging to be more uniform and tagging ratios to be larger than typically achieved when a fence is not available. For example, the mean tagging ratio was 6.9% in these tests, much higher than in most mark-recapture experiments. The Glendale River data give some idea of the enhanced accuracy to be expected. The population estimates from tagging in the cove and in the stream below the fence were 21% and 16% larger than the fence estimate, which in turn was 24% more than the fence count (Table 1). These are inadequate data on which to estimate a correction term but it is reasonable to assume that, had a fence not been used, the geometric mean error of all tests probably would have exceeded 30-35% in the sockeye estimates and 65% in the pink estimates.

SUMMARY AND CONCLUSIONS

1. Mark-recapture estimates of salmon escapements are almost always over-estimates of the true number. The tests reviewed here over-estimated sockeye by 21% and pinks by 45%. The two tests on coho over-estimated the population by an average of 6% and the three chum tests, an average of 4%. These tests are expected to produce more accurate estimates than most mark-recapture experiments because they used a fence. It is likely that mark-recapture methods will as often as not over-estimate sockeye populations by more than 35% and pink populations by more than 65%, based on these tests.

2. The precision of the over-estimates was poor in at least two sets of tests. The relative errors varied over ten-fold for three estimates of Babine Lake sockeye (20-98%). The precision was better for three years that Lakelse River pinks were estimated (27-42%). The estimates of Cultus Lake sockeye in 1938 and 1939 were 5% and 15% too large, respectively. The three estimates of Minter Creek chum were also relatively consistent and accurate, with errors of +4.6%, +9.4%, and -0.8%.

3. Application of the mark-recapture technique should be tempered with a respect for the assumptions being violated and the consequences of these violations. It should not be used as a standard in order to assess the accuracy or precision of other methods of estimating escapements. It should not be assumed to be always superior to methods such as live and dead counts on the spawning grounds. [In fact, H. D. Smith (unpublished data) obtained an almost perfect estimate of Lakelse River pinks in 1961 using strip counts and average stream life data. The lower 95% confidence limit of the mark-recapture estimate of the same run was about 50% more than the true number].

4. Where it is the only feasible method, the tagging and recovery periods should extend throughout the run and detailed data should be collected that will allow one to assess the errors as best as possible. The latter recommendation is important because the method apparently cannot be relied upon to be precise, based on the large variation sometimes noted between near-replicate tests.

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MAKING STOCK RECRUITMENT ANALYSIS WORK

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Introduction

The best way to determine the relationship between number of salmon spawning in an area, and the resultant production of adults is to experimentally allow different numbers of fish to spawn and to measure the resultant adult production. This is stock-recruitment analysis, which has become very popular in fisheries research in the last few years. Stock-recruitment has become popular in demersal and pelagic fisheries largely because the use of cohort analysis has enabled biologists to look much more directly at stock-recruitment, and they now find very strong stock recruitment relationships where it had often been assumed that recruitment was independent of stock size.

Stock-recruitment analysis has also had something of a revival in salmon due to evangelical work by Walters, Hilborn, and Ludwig on one hand, and by the court demands for justification and evaluation of escapement goals in Washington State on the other.

The intrinsic appeal of stock and recruitment has led many of us to try to do stock-recruitment on every possible data set, often without due consideration of all of the things that can go wrong. Unfortunately, there are a lot of things that can go wrong, and they all seem to have the nasty habit of causing us to underestimate the optimum escapement and overestimate the optimum harvest rate. The blind analysis of stock-recruitment data and application of the results to management needs a little tempering; we propose to review some of the things that can go wrong in stock-recruitment given the realities of the data available.

Stock-recruitment requires knowing how many fish spawned and how many

adults were produced, simple data but quite difficult to actually obtain. We then compare different spawning levels to see what differences there are in spawning stock size. We also need to make the assumption that there is no long term systematic change in the stock-recuitment relationship, a question that is difficult to address, but is known to occur because of changes in substock structure (Ricker and Smith 1975, Hilborn 1984).

Measurement of escapement is no simple matter, the methods employed may range from reasonably reliable (wier counts) to highly unreliable (counts of eagles, etc.). There are only a handful of salmon stocks where a long time series of accurate escapement data is available.

Measurement of recruitment is equally difficult. Recruitment is generally defined as the brood-year production of catch and escapement. Thus all variability in escapement counts become errors in recruitment as well. Assignment of catch to specific stocks is the most difficult step, and the source of much variability. Finally for species that return at more than one age, the ageing errors will be added on top of the errors in catch allocation. Table 1 summarizes the sources of error in salmon stock-recruitment analysis.

Errors in Escapement

Methods of measurement of escapement fall into two general classes - passage counts such as weir counts, test fisheries, or electronic counters, and on-site counts in rivers. Passage counts are subject to errors in actual counting of fish, and species identification.

Table 1: Sources of error in salmon stock-recruitment analysis

GENERAL	SOURCES OF ERROR
Escapement data	- individual counting error - errors in turnover rate estimates - species misidentification - ageing errors
Recruitment data	- escapement counting errors - catch allocation errors - ageing errors
Assumption of time independent stock-recruitment relationships	- substock changes - habitat changes - natural selection - change in competitions and predators

River counts generally rely on a series of counts over time, and a measurement of turnover in the spawning stock to assess average residence time. The reliability of the total count will be affected by the reliability of individual counts and the turnover rate. To our knowledge, there are no published statistics on the reliability of any method. Field staff will usually express an opinion of the reliability, but we suspect field staff tend to overestimate the reliability of methods they employ.

Errors in Catch Allocation

The two major sources of error in allocation of catch are ageing errors and stock assignment. Both types of errors may introduce a bias that cause us to underestimate the best spawning stock size.

If we assume that a portion of fish are incorrectly aged, in a two age stock such as chums where fish are generally age 3 or 4, then the estimated number of 3's and 4's are

$$(1) \qquad \hat{N}_3 = N_3 p + N_4 (1-p)$$
$$\hat{N}_4 = N_4 p + N_3 (1-p)$$

where $\hat{N}_3$ and $\hat{N}_4$ are the estimated number of 3 and 4 year olds in the catch. N_3 and N_4 are the actual number of 3's and 4's and p is the probability of correctly ageing a fish. The bias in the estimate of 3's:

$$(2) \qquad \frac{\hat{N}_3}{N_3} = p + \frac{N_4}{N_3}(1-p)$$

Thus only if $N_4=N_3$ is there no bias. The greater the difference in N_3 and N_4, the stronger the bias. When N_3 is less than N_4 then $\hat{N}_3 > N_3$. Small age classes will tend to be overestimated and large age classes will tend to be underestimated. This will cause us to underestimate the optimum spawning stock.

Allocation of catch between stocks can pose similar problems. If an estimate of stock composition is made by sampling the catch and then estimating the proportion of each stock, such as is commonly done by using scales, then exactly the same biases will be introduced, small stocks will be overestimated and large stocks will be underestimated. These errors are particularly bad for stocks that constitute a small proportion of the total run. Thus we believe the IPSFC estimates of catch from off-cycle sockeye runs are likely to be high because the off-cycle runs are small in relation to other stocks.

Another catch allocation method that imposes similar biases is the method which assumes that a stock contributes a constant proportion of the catch to each area in which it occurs. If a stock is weak, its allocation will be too high; if the stock is strong, its allocation will be too low.

The method of allocation that does not seem to have as many biases is allocation of catch proportional to escapement. The run reconstruction method practiced by Washington State and B.C. follow this method.

How Important Are Errors ?

For simplicity, let us assume that we will do a Ricker stock recruitment analysis on data generated from a real Ricker curve given by equation 3.

$$(3) \qquad R = Se^{a-bS_e v}$$

where R is the true number of recruits, S is the true number of spawners, a is a parameter of productivity, b is a parameter of scale, and v is a normally distributed random variable with a mean of zero and a standard deviation of σ_v. Further let our estimate of spawning stock be estimated as

$$(4) \qquad \hat{S} = Se^{(w - \sigma_w^2/2)}$$

where w is normally distributed with mean zero and standard deviation σ_w and let estimated catch be

$$(5) \qquad \hat{C} = Ce^{(\mu - \sigma_\mu^2/2)}$$

where μ is normally distributed with mean zero and standard deviation σ_μ. The σ_μ^2/w and $\sigma_w^2/2$ correction terms are applied because the expected value of e^w or e^μ is not 1.0, but the expected value of

$e^{w-\sigma_w^2/2}$ and $e^{\mu-\sigma_\mu^2/2}$ is 1.0.

The total recruitment is

(6) $$\hat{R} = \hat{C} + \hat{S}$$

Note that the spawning stock $\hat{S}$ that goes into the recruitment is not the same $\hat{S}$ that is used as the brood year spawning stock.

We can now do Monte Carlo simulations to find out how sensitive our estimate of optimum escapement is. While there are thousands of possible combinations to try, there are three parameters of significant interest: the standard deviation of escapement counts σ_w, the standard deviation of catch estimates σ_μ and the amount of variation in the historical escapements.

Results

Monte-Carlo simulations were performed assuming a stock where a=1.5 and b=1. The optimum spawning stock is about .4. Table 2 shows the results when the average historical spawning stock is very low $\bar{S}$=.1 and there is little variation in the stock size σ_S=.01. There is no process error (σ_v=0). We chose spawning stocks from a normal distribution with a mean equal $\bar{S}$ and a standard deviation of σ_S; thus we do not incorporate into our analysis the biases due to non-independence discussed by Walters (this volume). Table 2 shows the average yield loss for 6 levels of σ_w as σ_u, the average optimum escapement estimate bias and the average

Table 2: Simulation results $\bar{S}$=.1, σ_s=.01, σ_v=0

PROPORTION OF POTENTIAL CATCH OBTAINED

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	1.00	.48	.42	.42	.45	.46
.2	.51	.47	.44	.46	.45	.46
.4	.37	.48	.46	.43	.45	.49
.6	.28	.41	.44	.44	.45	.44
.8	.30	.40	.48	.46	.46	.43
1.0	.17	.34	.42	.42	.45	.48

ESCAPEMENT BIAS

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	1.00	.24	.20	.21	.21	.20
.2	.80	.24	.21	.22	.22	.22
.4	.81	.23	.23	.22	.22	.24
.6	.36	.26	.22	.22	.23	.21
.8	.87	.23	.25	.22	.20	.18
1.0						

HARVEST RATE BIAS

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	1.00	1.27	1.34	1.36	1.39	1.43
.2	.99	1.27	1.34	1.36	1.38	1.42
.4	.93	1.26	1.31	1.36	1.38	1.42
.6	.89	1.19	1.33	1.35	1.38	1.42
.8	.79	1.21	1.27	1.34	1.39	1.42
1.0	.51	1.16	1.31	1.32	1.37	1.41

optimum harvest rate bias. Note that the average yield is about 40 percent of the optimum; the optimum harvest rates are biased high and the optimum escapements was biased low. The escapement counting error is much more serious than the catch counting error.

We might stress that the σ_s-.01 used in this analysis is quite critical; it is most unlikely that there would be such poor contrast for a real stock. With such poor contrast in stock sizes, the lowest level of escapement counting error was sufficient to cause very serious bias and the bias did not get much worse with increasing levels of escapement counting error.

Table 3 shows the results when process error is included (σ_v=.3 $\bar{S}$=.1, σ_s=.01). The results are quite similar except in the presence of no escapement or catch error. The estimates are very severely biased. In fact the bias is greater without escapement or catch errors than when they are present. This is apparently because the optimum escapement is estimated as a non-linear function of the Ricker a and b parameters. Though these parameters should be unbiased, a non-linear function of them is not. Thus even in the absence of escapement or catch counting errors, Ricker stock-recruitment analysis is biased.

The results of Tables 2 and 3 are for unrealistically low levels of variation in historical spawning stock. Table 4 shows results when there has been much more variation in true spawn stock size (σ_s=.05). The same biases are present but now the level of escapement counting error does affect the bias. There is no discernable trend due to levels of catch counting errors.

Table 3: Simulation results $\bar{S}$=.1, σ_s=.01, σ_v=.3

PROPORTION OF POTENTIAL CATCH OBTAINED

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	.25	.49	.43	.42	.42	.44
.2	.24	.46	.45	.43	.44	.45
.4	.22	.45	.44	.42	.45	.46
.6	.19	.37	.45	.42	.43	.42
.8	.21	.39	.45	.45	.43	.43
1.0	.18	.31	.41	.43	.44	.45

ESCAPEMENT BIAS

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	978.98	.22	.18	.20	.20	.19
.2	.30	.21	.22	.21	.20	.20
.4	.51	.27	.20	.20	.20	.22
.6	1.16	.22	.22	.20	.20	.19
.8	.83	.24	.22	.20	.21	.17
1.0	755.55	.24	.19	.21	.22	.20

HARVEST RATE BIAS

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	.79	1.18	1.25	1.28	1.31	1.34
.2	.88	1.19	1.24	1.27	1.29	1.33
.4	.75	1.11	1.23	1.27	1.30	1.32
.6	.49	1.14	1.22	1.26	1.30	1.33
.8	.56	1.13	1.20	1.26	1.30	1.33
1.0	.32	1.06	1.23	1.22	1.29	1.33

Table 4: Simulation results $\bar{S}$=.1, σ_s=.05, σ_v=.3

PROPORTION OF POTENTIAL CATCH OBTAINED

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	.63	.69	.63	.57	.53	.50
.2	.48	.60	.59	.57	.55	.50
.4	.48	.52	.63	.59	.53	.53
.6	.42	.58	.58	.55	.53	.51
.8	.38	.50	.53	.56	.53	.54
1.0	.46	.39	.62	.53	.53	.53

ESCAPEMENT BIAS

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	.94	.61	.38	.32	.25	.22
.2	.79	.65	.38	.29	.27	.25
.4	1.05	.81	.38	.29	.27	.28
.6	.93	.46	.35	.29	.27	.22
.8	1.45	.34	.44	.31	.27	.24
1.0	.63	.51	.40	.28	.30	.26

HARVEST RATE BIAS

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	.95	1.00	1.10	1.19	1.24	1.32
.2	.97	.99	1.09	1.20	1.25	1.31
.4	.93	.97	1.09	1.21	1.25	1.30
.6	.91	1.01	1.14	1.20	1.26	1.30
.8	.92	1.08	1.09	1.18	1.25	1.30
1.0	.91	.97	1.07	1.19	1.25	1.29

All of the results examined so far are for cases where average spawning stock size is far below the true optimum. Table 5 shows a case where average spawn stock is slightly above the optimum ($\bar{S}$=.5 σ_s=.2) and there is great contrast in stock sizes. The bias in this case is very slight and actually decreases with increasing errors in escapement counts.

Discussion

We have demonstrated that the stock-recruitment estimates of optimum escapement and optimum harvest rate may be seriously biased, a finding shown previously by Walters and Ludwig (1981). The amount of bias depends upon the historical pattern of spawning stocks; if spawning stocks have been near optimum, the bias will not be serious.

Errors in catch estimation are much less serious than errors in escapement, although we have not considered the systematic errors in catch estimation discussed earlier, and these systematic errors will undoubtedly cause more severe biases than those presented in this paper.

The fact that the Ricker estimates are biased in the absence of any escapement errors, catch errors or serial correlation in spawning stocks is new, but probably not of greater importance since it is so unlikely to have no errors.

It is clear from these results that a great deal of caution should be used in interpreting stock-recruitment data. A rigorous analysis should include estimates of catch and escapement errors, as well as any assessment

Table 5: Simulation results $\bar{S}$=.5, σ_s=.2, σ_v=.3

PROPORTION OF POTENTIAL CATCH OBTAINED

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	.94	.96	.92	.94	.92	.87
.2	.88	.93	.96	.94	.91	.92
.4	.89	.91	.93	.94	.88	.86
.6	.89	.89	.92	.85	.89	.86
.8	.80	.86	.84	.87	.92	.87
1.0	.83	.85	.87	.87	.89	.83

ESCAPEMENT BIAS

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	.92	.96	.93	.91	.86	.94
.2	.98	.97	.96	.89	1.02	.94
.4	.91	.92	.92	.91	.89	1.04
.6	.92	.87	.91	.85	.87	.92
.8	1.02	.89	.95	.89	.94	.92
1.0	.88	.88	.89	.89	.81	1.05

HARVEST RATE BIAS

Catch (σ_u) Error	Escapement error (σ_w)					
	0	.2	.4	.6	.8	1.0
0	.95	.96	1.01	1.09	1.12	1.21
.2	.91	.95	1.01	1.11	1.09	1.17
.4	.95	.95	1.01	1.08	1.14	1.17
.6	.93	.98	.99	1.06	1.15	1.20
.8	.88	.96	.98	1.04	1.11	1.18
1.0	.93	.94	.87	1.00	1.12	1.11

systematic errors in the data collection. Monte-Carlo simulation should be performed to see how much bias would be expected. Ambiguous results could easily arise. If for instance there are large errors in escapement counts and the optimum stock size appears to be near the historical stock size, the real optimum could be much higher and the estimated optimum be severely biased low. It is also possible that the true optimum is near the estimated optimum and there is no bias. The current controversy over Skagit River escapement goals in Washington State could well fall into this category. We are reluctant to generalize about the utility of stock-recruitment. Obviously improved escapement estimates will help, but serious bias occurs with even low levels of escapement counting error. Large variation in spawning stocks are more important; if we have large escapements on occasion, it is unlikely we will seriously underestimate the optimum stock size.

The biases in the optimum harvest rate deserve some discussion as well. The harvest rate depends only on the Ricker a value and is much less prone to bias than the optimum escapement which depends on both Ricker a and b. While a typical optimum escapement might be estimated at 30 percent of the true value (70 percent too low), the optimum harvest rate would be estimated only 15 percent too high. Additionally, the bias in the optimum harvest rate is more sensitive to the level of escapement count error, so that reduction in escapement errors leads to good reduction in harvest rate bias. Fishing policies based on harvest rates rather than escapement goals will probably perform better when there is considerable uncertainty about the reliability of stock and recruitment.

We have only explored some of the possible errors that can affect

stock-recruitment analysis. Every stock is different and biologists concerned with the management of specific stocks should look quite carefully at the elements of their stock-recruitment data sets and spend a considerable amount of energy in simulations of alternative error assumptions.

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DEVELOPMENT OF A STATISTICALLY VALID BASIS FOR A STREAM INDEXING SYSTEM TO ASSESS SPAWNING ESCAPEMENTS IN B.C. SALMON: A TECHNICAL PROPOSAL AND WORK PLAN

by

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Ludwig and Walters (1981) have recently discovered that salmon escapement counting and recording errors, of magnitudes typical for routine field assessments in British Columbia, are likely to result in severely biased and misleading estimates of production parameters and even trends in stock size over time. The Pearse Commission on Pacific Fisheries Policy (Pearse 1982) recommended that new monitoring programs be developed, and one suggestion has been to concentrate on accurate measurement of escapement levels in a subset of "index streams" that are thought to have typical production patterns and temporal trends. The validity of this approach depends on two empirical questions.

(1) can production parameters (i.e. stock-recruit parameters) for non-index stocks be predicted from the behavior of index stocks and "environmental covariates", such as watershed size, that are bound to cause variation in productivity among stocks?; and

(2) do there exist clusters of stocks with highly correlated temporal behavior (trends) such that one or a few members of each cluster are indeed informative about the behavior of the rest?

Existing escapement records and methods of assessing stock contributions to catches are not adequate to definitively answer these questions, but may provide some hints at least about how many index streams may eventually be needed.

This proposal is to conduct Monte Carlo simulations and analyses of historical escapement data, so as to produce a background paper[a] that will attempt to resolve the following questions:

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[a] Editors' Note: This background paper, entitled "Design of Stream Indexing Systems for Assessment of Escapements in B.C. Salmon" has been prepared by Dr. Walters for internal (DFO) use.

(1) What is the appropriate definition of "spawning stock" for management purposes, considering that nature has not cooperated in providing many of the unit stocks assumed in most fisheries theory?

(2) How are future losses in potential catch due to errors in assessment of optimum spawning stock levels likely to be affected by:

a) changes in the precision (average percentage error) of spawning stock estimates;
b) error in estimates of stock contributions to mixed fishery catches; and
c) variation in spawning stock levels due to uncontrolled factors or deliberate experimental manipulations?

(There is a trade-off between factors (a) and (c); less precision is needed if greater actual variation is permitted or induced.)

(3) How important is it to have accurate escapement estimates, as opposed to precise measurements of relative stock size over time?

(4) How would improvements in measurement precision and accuracy affect other major uses of escapement data, including:

a) evaluation of general trends in abundance over time;
b) assessment or regulatory performance (i.e. effects of measures such as closures and gear restrictions);
c) forecasts of future stock sizes; and
d) determination of impacts due to disturbances such as enhancement and habitat change?

(5) How should a stream indexing pilot project be designed so as to provide a valid basis for deciding what system to use province-wide when the design factors include:

a) number of streams requiring simultaneous, accurate measurements (initial number of index streams);
b) number of years needed to complete the project and;
c) the necessity of coordinating the project with ongoing fisheries management, so as to provide strong and deliberate variation in escapement levels from year to year through changing exploitation rates?

(6) Based on analysis of historical stock-recruitment data from one region (Georgia Strait pink and sockeye salmon stocks), how much stock-to-stock variation can be expected in recruitment parameters, and is this variation associated with easily measured factors such as watershed size?

(7) Based on cross-correlations among all the escapement time series that are now available in computerized form from BC-16 records, what clustering of stocks would now appear best as a basis for coastwide indexing, and how should each stock be ranked as a candidate for indexing based on:

a) its correlation with other stocks over time; and
b) its accessibility for counting and/or maintenance of automatic counting equipment?

Questions (1) to (5) above will involve essentially a review and restatement of research results already obtained by Ludwig and Walters (1981), along with some Monte Carlo simulations to demonstrate particular points such as the importance of causing deliberate variation in escapement levels to the pilot index streams. Item (6) will involve a reanalysis of data now on computer files at the University of British Columbia (UBC). Item (7) will require cooperation from F.Y.C. Wong (Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B.C.) in making BC-16 data files available for analysis using time series programs on UBC's Amdahl computer.

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ESCAPEMENT ESTIMATION: FROM AN ECONOMICS PERSPECTIVE

by

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Escapement Estimation: From an Economics Perspective

by Anthony T. Charles

Escapement estimation and stock-recruitment analysis are not topics of burning interest amongst economists. Perhaps they should be. Not only are these questions crucial to an understanding of the major input to economic analyses of fisheries, namely the fish stock, but decisions relating to the optimal extent and quality of escapement determination and recruitment prediction are indeed fundamentally economic ones.

If escapement data could be effortlessly and costlessly collected, and if recruitment projections could be made without error, then statistical analysis and subjective decision-making would be unnecessary; the world would rejoice, although unemployment would increase substantially amongst stock-recruitment analysts. Fortunately (for some), the reality is a good deal messier. Escapement information is collected and/or guessed at, with varying degrees of accuracy and with varying costs. Recruitments, and hence future stock sizes, are projected from escapement data, with very mixed success.

Decisions are made on the basis of these fish stock predictions: decisions on the part of fishermen concerning vessel investment plans, fishing plans and even career plans; decisions on the part of fisheries management concerning regulatory plans and fishery openings. If fish stock predictions are incorrect, wrong decisions are made and society pays, through misallocation of human resources and capital, or even through fish stock extinction in extreme cases. These costs to society, while difficult to measure, are certainly very real.

It is well known that mixing costs and benefits together, in any proportions, produces an economist. This is such an instance. The economist contrasts immediate and ongoing costs associated with escapement estimation (labour costs, survey costs, tagging costs, test fishery costs, etc.) with the long-term benefits of improved stock predictions (reduced misallocation of labour and capital through improved investment and management decisions). These latter benefits can be seen either as the "value of information" to the fishery, or inversely as a reduced risk of incorrect decisions.

The escapement estimation problem, then, is essentially one of cost/benefit analysis. The goal is to choose the overall data collection and analysis package to maximize the difference between benefits to society and total costs. Put another way, the question is: what level of escapement accuracy is 'optimally' required, to produce the maximum net benefits from the fishery? Of course, this concept is implicit in most discussions; every fishery analyst would like better escapement data, but no one proposes lining the coast with fishery officers or hiring the air force to look for spawners.

A bit of economics could be useful in performing a suitable cost/benefit analysis of the escapement estimation problem. In their simplest form, such cost/benefit analyses are notorious for tending to ignore less tangible factors (such as the esthetic considerations of stock extinction) and for downplaying the risk factors arising from economic and biological uncertainties. However, a related methodology, 'decision analysis', can be used to better address these components of the problem. Decision analysis provides a systematic framework for decision-making, one that can incorporate all objectives considered important and deal with risk and other factors which modify the simple optimization problem inherent in making a decision. Essentially, the approach is one of generalized cost/benefit analysis.

Within this broad framework, what are the basic aspects of the escapement estimation problem? These can be summarized as follows:

(i) determination of the optimal management policy for any set of escapement data and any level of uncertainty in that data;

(ii) determination of the expected future benefits of various reductions in escapement uncertainty, and the variance in these future benefits;

(iii) determination of the initial and ongoing costs necessary to achieve the reductions in escapement uncertainties described in (ii);

(iv) determination of the decision-makers' (or society's) risk preference (i.e., the extent of risk aversion);

(v) insertion of (i)-(iv) into the decision analysis framework to obtain an overall evaluation of each estimation scheme;

(vi) selection of the optimal scheme based on maximizing a multi-objective "utility function", which incorporates each of the management objectives (a healthy resource, full resource utilization, etc.), with appropriate weighting factors applied to each objective.

Essentially, fisheries decision-makers concerned with stock management are faced with formulating plans based on resource stock status data. For salmon, this is typically escapement data; given a set of such data, the manager hopefully will develop an 'optimal' exploitation policy. The point of (i) above is that, to be 'optimal', such a policy must consider explicitly the uncertainty in the data, as well as the data themselves.

Once the management plans are known (at least theoretically) for various possible levels of uncertainty in the data, computer simulation techniques can be used to analyse the predicted effects of a reduction in the degree of uncertainty in escapement estimates. One must average the benefits over many possible outcomes, depending on what future environmental fluctuations nature may produce (see below).

The expected benefits arising from increased accuracy in the estimation process must be balanced by the various costs involved in achieving improvements. These costs are calculated in step (iii); this involves consideration of direct costs (tagging, counting, etc.) and 'opportunity costs' arising when resources (PY's, capital) have to be diverted from other activities.

Determining the "risk preference" is typically a subjective exercise, in which one must address such questions as: How do we evaluate an estimation scheme that has a 75% chance of increasing net benefits accruing from the fishery, but a 25% chance of being a total waste of money? Such questions are important because there is indeed a possibility that precise escapement estimates would do nothing to help the fishery. Parameters may be so poorly known and biomass fluctuations so great that an optimal management policy is not clear (and hence target escapements are unknown) even with accurate escapement estimates. Indeed, if nature happens to produce a series of 'unusual' (low-probability) recruitment values immediately after fishery management has increased the precision of its escapement estimation, this could lead to apparently more reliable 'optimal' escapement levels actually being worse than those obtained with less precise data. This is not to say that such events are likely, but they are possible, and should be taken into account. If government insists that improved escapement estimation procedures must produce net benefits to society in order to be implemented, no such costly procedures could ever be approved.

Steps (v) and (vi) involve the final analysis of each possible estimation technique, and a comparison between these. Costs of each estimation procedure are subtracted from expected benefits (adjusted for the risk of poor results). The outcome is the 'score' awarded to that proposal, these scores are then compared across all possibilities until a winner is found. It is noted that the scores actually can be based on a weighted combination of multiple management objectives, where more than simple economic factors can be included.

This framework is very general and relatively complex. If carried out in full, each step in the procedure can be time-consuming and expensive. Yet such a logical step-by-step approach, whether done analytically on computers or heuristically in discussion groups, is necessary to achieve a reasonable estimation design and to have some idea how well that design will perform.

To provide a specific application of this approach, consider the question of stream or stock indexing, defined here as the use of data for a subset of streams or fish stocks to estimate overall escapement in a larger area. This concept, basically one of 'sub-sampling', is appealing in that it allows fishery management to concentrate effort on measuring escapements in fewer systems. This, of course, also generates statistical inaccuracies through the lack of direct measurements in non-index streams or stocks. While an index can be used quite easily to draw attention to fish stock trends, many management needs require estimation of absolute escapement numbers. To accomplish this, one must use base year data or annual tagging analyses to calibrate the index system. However, such a calibration may not hold from year to year if fluctuations in relative abundance between stocks are serious. Indeed, there appear to be a large number of difficulties with

indexing systems; this paper is designed not to discuss such questions in detail but to point out the elements of economics that arise. To accomplish this, suppose that the following gross simplifications can be made to the fishery management problem:

Assumption 1. Each season's fishing plan must be based on run expectations, which depend in turn on past escapement estimates and on the uncertainty in these estimates (for example, greater uncertainty may imply more cautious plans).

Assumption 2. Options for overall escapement estimation are determined by selecting a combination of (i) a sample of streams (or fish stocks) to survey; and (ii) a survey quality (or precision) to be applied to each stream (or stock). For example, the current methodology for Canadian west coast salmon stocks could be characterized as one with a large sample size but low precision, while the opposite extreme would involve choosing a single stream or stock as the 'index of escapement' and then determining its spawning population very precisely.

Assumption 3. The annual cost of surveying is a function of both the total number of streams (or stocks) in the survey sample, and the survey precision per stream. Costs of calibrating the indexing system, using 'baseline' data from other sampling methods to determine appropriate scaling factors, are assumed to be included in these annual costs.

Assumption 4. The attitude of society (or Fisheries decision-makers) towards the success or failure of the survey methods can be summarized in a 'Utility function' $U(\cdot)$ which weights possible results in an appropriate manner, to reflect risk preferences, political considerations, etc.

With these assumptions, it is possible to formulate a general, much simplified mathematical framework for the economic optimization of escapement survey design. First, make the following definitions:

N = total number of streams (or stocks)
n = number of index streams (or stocks)
p = proportion of streams being surveyed = n/N
q = 'quality' of the survey, per stream or stock, scaled between 0 and 1
a = discount factor; $a=1$ if a dollar 100 years from now is as important to society as a dollar now; $0 < a < 1$ otherwise.
$\underline{x}$ = $(x_1, x_2, \ldots, x_N)$ = set of current (base year) escapement data

$\sigma(p,q)$ = uncertainty in the estimate of total escapement, as a function of survey proportion p and survey 'quality' q.
$c(n,q)$ = $c_1(n)\, c_2(q)$ = annual cost of surveying n index streams, with survey precision q.

$A(\underline{x}, \sigma)$ = optimal management plan given current escapement $\underline{x}$ and uncertainty level σ
$V(\underline{x}, \sigma)$ = the value of the fishery which will be obtained, given initial escapements $\underline{x}$, measured with uncertainty σ, assuming the optimal plan A is followed

Then the optimization problem can be written:

$$\text{Maximize} \quad \{ EU(V(\underline{x}, \sigma)) - (\frac{1}{1-a}) c_1(n) c_2(q) \}$$

$$o \leq p \leq 1$$
$$o \leq q \leq 1$$

where "U" is the utility function (see Figure 1), "E" is the expectation operator, which averages the value of the fishery over all possible future fish stock sizes, and the $(\frac{1}{1-a})$ term results from summing annual survey costs over all future years.

As an example of this, suppose that the survey quality is fixed at q=1. Then Figure 2 depicts possible benefits and costs as functions of the proportion of streams being surveyed, p. The optimal extent of the stream indexing system, p*, occurs where the difference between benefits and costs is maximized; this can occur anywhere between p=0 and p=1, depending on the functions U, V, σ, c_1, and c_2. In Figure 2, the possibilities p*=0 and 0<p*<1 are shown, for two particular 'expected benefits' functions.

Of course, the difficult aspects of survey design lie not in setting out the general framework, but in determining, in quantitative terms, the cost and benefits together with the optimal management plan, for each of the many possible sampling designs.

There has been relatively little analysis of escapement estimation questions in general, and stream indexing in particular. There is a widespread acceptance that escapement data need improvement, and yet few if any studies have fully documented the costs and benefits of such improvements. If accurate escapement estimates will substantially improve fishery returns, solid analysis will aid in lobbying for funding to carry this out. If, on the other hand, obtaining exact escapement numbers is not worth the cost to society, surely this too should be known. In any case, there is some complex analysis to be done; what we know is dwarfed by what we do not know. Hopefully, a framework of economic analysis may play a useful role in the escapement estimation problem, as it already does in the broader questions of optimal fisheries management.

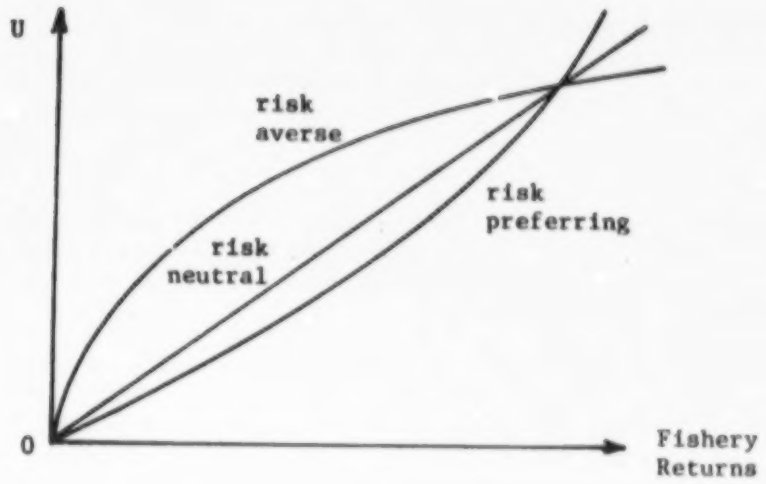

Figure 1. Relationships between utility function and fishery returns.

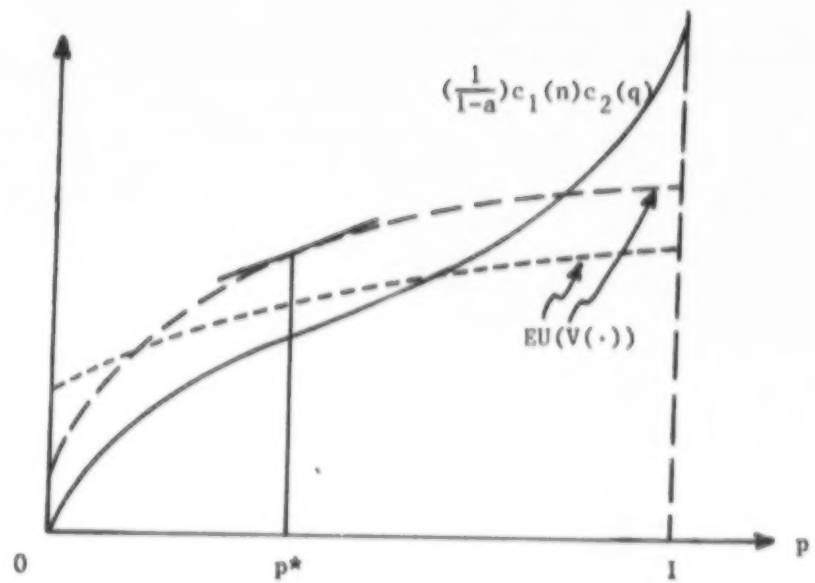

Figure 2. Possible benefits and costs as functions of proportion of streams being surveyed.